ECE 665 (ESS)

Radio Frequency Identification (RFID) Fundamentals and Applications

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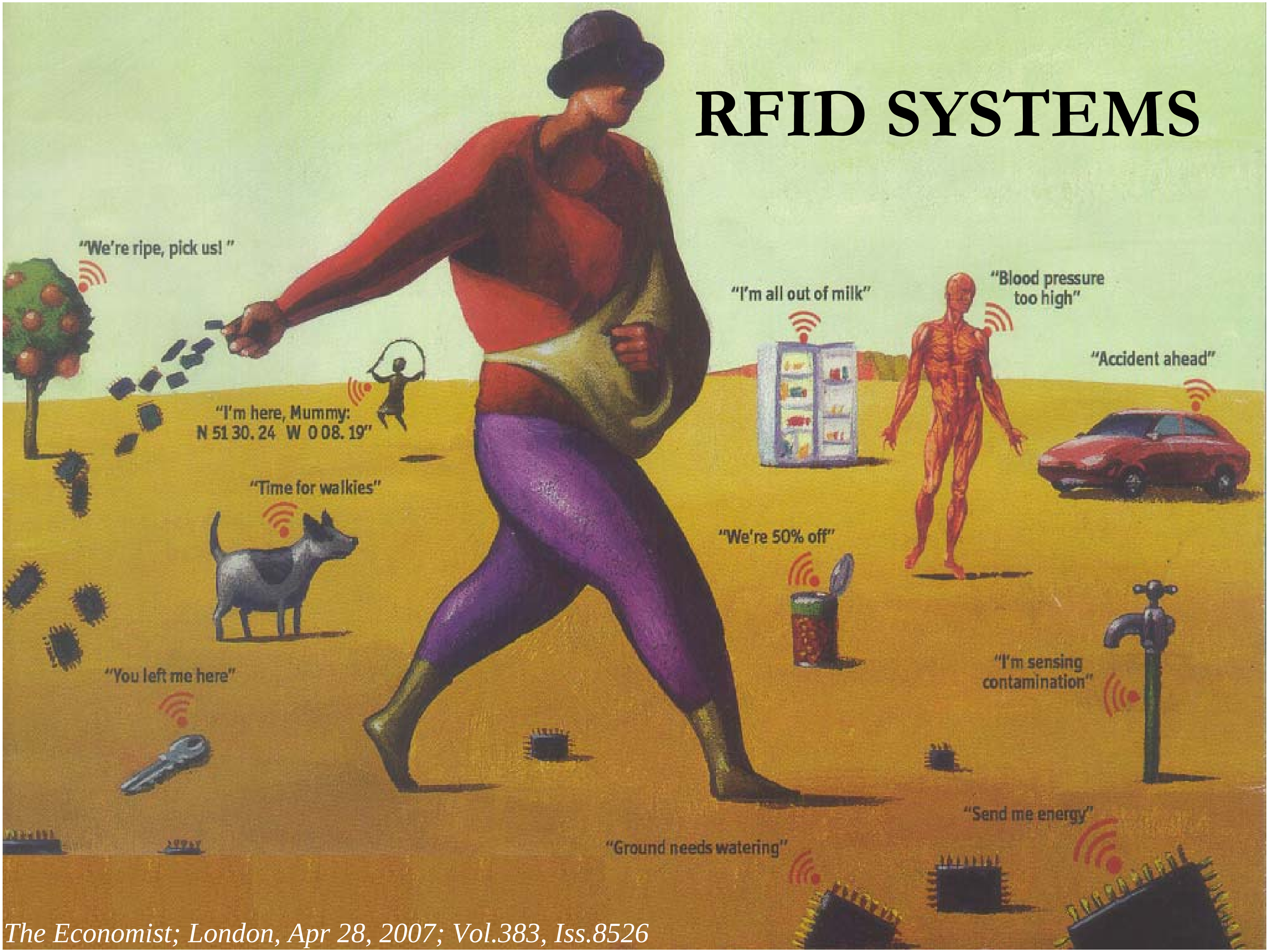
Thanks to Faisal and Didem for providing a significant part of this presentation.

RFID SYSTEMS



The Economist; London, Apr 28, 2007; Vol.383, Iss.8526

Outline

- What is RFID.
- RFID Applications.
- RFID Devices (Interrogator & Transponder).
- Different Frequency Bands and Standards.
- System Design for Passive and Semi-Passive Systems.
- Passive Tag Building Blocks.
- Future research Topics.

What is RFID

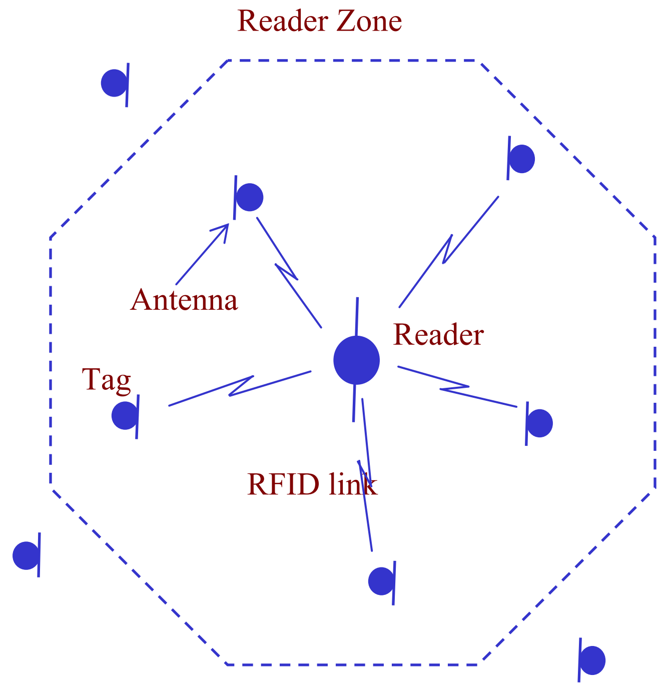
- **Radio Frequency Identification**
  - Technology uses radio waves to transmit key information over short distances.
  - Information describes identity, location, and/or condition of physical objects.
  - Operability in non line of sight environments
  - Similar systems: Bar-code scanners, Magnetic strip readers, Biometric identification, …

RFID Concept

- System elements: Reader (Interrogator) and Tag (Transponder).

- Master/slave operation.

- The Reader detects any Tag within its zone of operation.

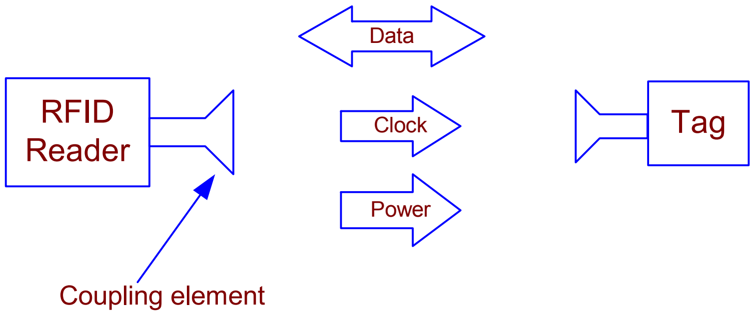


K. Finkenzeller, *RFID Handbook,* 2nd ed., Wiley, West Sussex, England 2003

RFID Concept

- ❑ Uplink:
  - Reader sends commands, clock, and power needed to operate the tag.
  - Modulation scheme: ASK, PWM or FSK modulation.

- ❑ Tag is activated by the RF signal.



- ❑ Downlink:
  - Tag sends response (simple Id, or sensor data).
  - Modulation scheme: BackScatter modulation.

RFID Applications

- **RFID systems are becoming a part of our everyday life: at home, work, in hospitals, post offices, supermarkets, tracking our pets, implanted in human bodies and many more possibilities.**

- **The application areas could be categorized:**

  - **Medical**
  - **Tracking**
  - **Identification**
  - **Sensor Applications (Data Acquisition and Monitoring)**
  - **Supply Management**
  - **Security/Access Control**

RFID Applications: Overview

- Access Control & Security:
  - Electronic Article Surveillance.
  - Employee Entry / ID Badges.

RFID Applications: Overview

- Sensors / Data Acquisition:
  - Biomedical Monitoring.
  - Oil Drilling Pipe Monitoring.
  - Civil Engineering – Stress.

- Chip wafer manufacturing:
  - Tagging at the tray level to insure work processes are performed.

RFID Applications: Overview

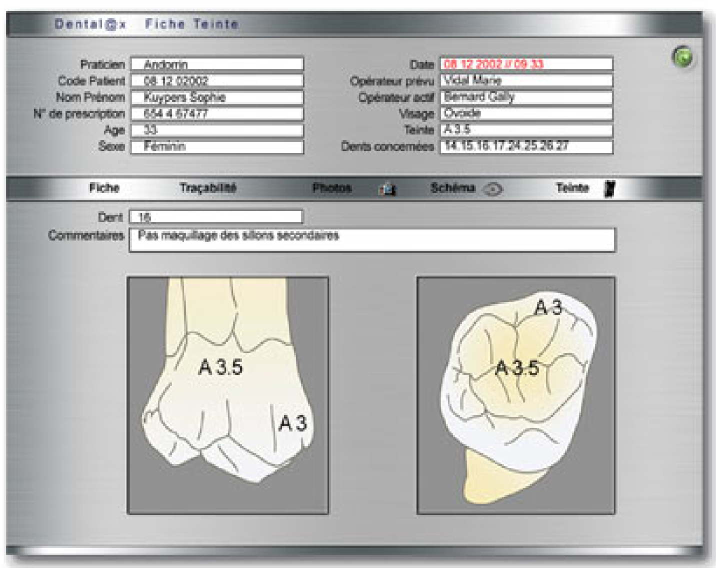
- Logistics / Tracking :
  - Animal Tracking / Vaccination History.
  - Supply Chain Management.
  - Airline Baggaging.

RFID Applications: Case Studies

❑ **Dental Prosthesis Tracking:**

- **The Chip is embedded in dental prosthesis (crown or a bridge).**

- **Each time an operation is carried out, it is recorded in the chip.**



- **A reader and the USB connected PC is used to track the operations on the prosthesis.**

- **Memory of the chip varies from 2 to 32 kbits.**

http://www.dentalax.com
http://www.rfidjournal.com/article/articleview/1206/1/1/

RFID Aplications: Case Studies

Ticket Anti-Counterfeiting

- In worldwide events, large numbers of tickets are sold. RFID technology is used to
  - speed-up admissions to the event
  - Prevent fake ticketing
  - Prevent mechanical wear/tear of tickets
  - Secure the data through encryption

- 2008 Beijing Olympics will employ RFIDs:
  - 7 million tickets will be tagged with RFID's to prevent ticket fraud and to enhance security

- 2006 FIFA World Cup Employed RFID Systems

SDA Asia Magazine:
www.sda-asia.com/sda/news/psecom,id,15361,srn,4,nodeid,1,_language,Singapore.html

RFID Applications: Case Studies

Fast&Secure Credit Payment

- **MasterCard introduced contactless wireless payment tool *Paypass Technology* in 13 countries worldwide.**
- **Paypass cards or key fobs are equipped with 13.56MHz RFID tags. The read range is 2-3 cm. The RFID inlay employs *cryptographic authentication* to prevent modification of chip data and secure the transactions.**
- **Instead of the regular card slip, customers will use their Paypass to "tap" the reader.**
- **The card or key fob sends payment details to the reader through wireless carrier, the reader transmits this information to an intermediate terminal and then to the MasterCard network to finish the transaction.**

http://www.mastercard.com/us/personal/en/aboutourcards/paypass/index.html
http://www.rfidjournal.com/article/articleview/2112/1/1/

RFID Applications : Case Studies

Fast&Secure Credit Payment (Cont'd)

- **Several fast food stations, pharmacies, movie theaters, football stadiums supermarkets are already equipped with Paypass readers.**
- **New York City Subway trial employs subway turnsiles that have readers. MasterCard – Citibank Paypass is expected to speed up the subway entrance lines and relieve the crowd at NYC business hours.**

- **American Express started a similar technology called *ExpressPay*.**

http://www.mastercard.com/us/personal/en/aboutourcards/paypass/index.html
http://www.rfidjournal.com/article/articleview/2112/1/1/

RFID Applications : Case Studies

Smart Fridge with RFID

- **Samsung is developing a refrigerator that employs RFID technology, to be available in 2009.**
  - **The fridge will monitor the inventory levels and notify the user for the items running low.**
  - **The food items should be tagged by the food suppliers**
  - **The fridge will possibility transmit this data to the cell-phone of the user through a Bluetooth link.**
  - **A user interface will generate possible recipes or shopping lists based on the data the fridge provides**

http://www.rfidgazette.org/2007/01/new_diet_courte.html

RFID Applications: Case Studies

Cookware with RFID

- **VitaCraft produced Robotic Cookware with RFIQin tecnology that employs RFID tags and readers to follow the proper cooking steps and temperatures**
- **Recipe cards include a tag, when swept under the pan handle, reader at the handle reads the recipe ID.**

Pan reader reads the tag in the recipe card

- **The tags have a temperature sensor, hold the read/write data, and can hold 23 cooking steps in a recipe.**
- **The cooktop has a software that limits the power and temperature according to the recipe in the pan RFID tag and that follows the cooking steps in the read recipe.**

http://www.vitacraft.com/rfiq/rfiq.html#

RFID Applications: Case Studies

Accurate Timing for Athletes

- **ChampionChip Technologies employ RFID chips from Texas Instruments to determine the accurate timing of athletes in triathlons, marathons, bike races and several sport events all around the world**

- **The system consists of synchronized antennas, readers, tags and a dedicated software that is used to handle the data.**

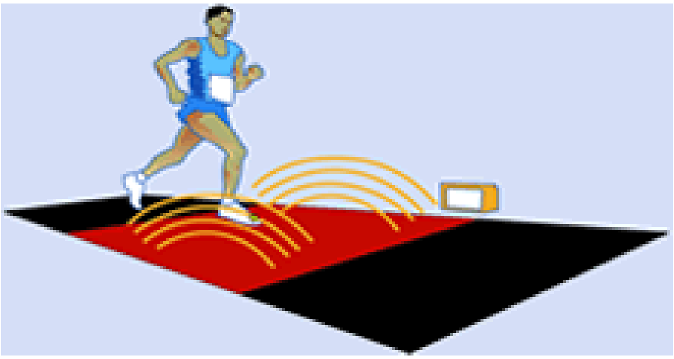
Passive Tag, is powered by the reader's wireless signal

http://www.championchip.com/home/index.php

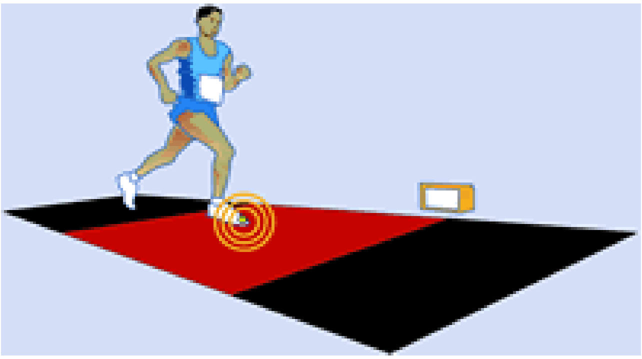
RFID Applications: Case Studies

Accurate Timing for Athletes (Cont'd)

- The reader and its antenna are embedded in the carpet at the finish lines or check points.
- The whole procedure lasts only 60 miliseconds



The reader detects the tag on the athlete and powers it up through the wireless carrier



The tag responds to the reader's signal and transmits its unique ID number

http://www.championchip.com/home/index.php

RFID Applications : Human Implanting

History

- In 1998 cybernetics professor Kevin Warwick had implanted with a tag and started using RFID systems in his home, office and car

- In 2004 VeriChip corporation started the first FDA approved human implantable chips. Around 2000 people already have been implanted.

- Since then, several do-it-yourself taggers emerged such as Amal Graafstra, who bought industrial tags & readers to build their own RFID systems.

“RFID Inside” and “Hands on RFID” , IEEE Spectrum March 2007

Human Implanting

Applications

***Medical*:**

- **The unique number in the tag points to the medical record of the patient in the database.**
- **Useful when the patient is unconscious or for patients with chronic diseases**
- **VeriChips are produced mainly for this application**

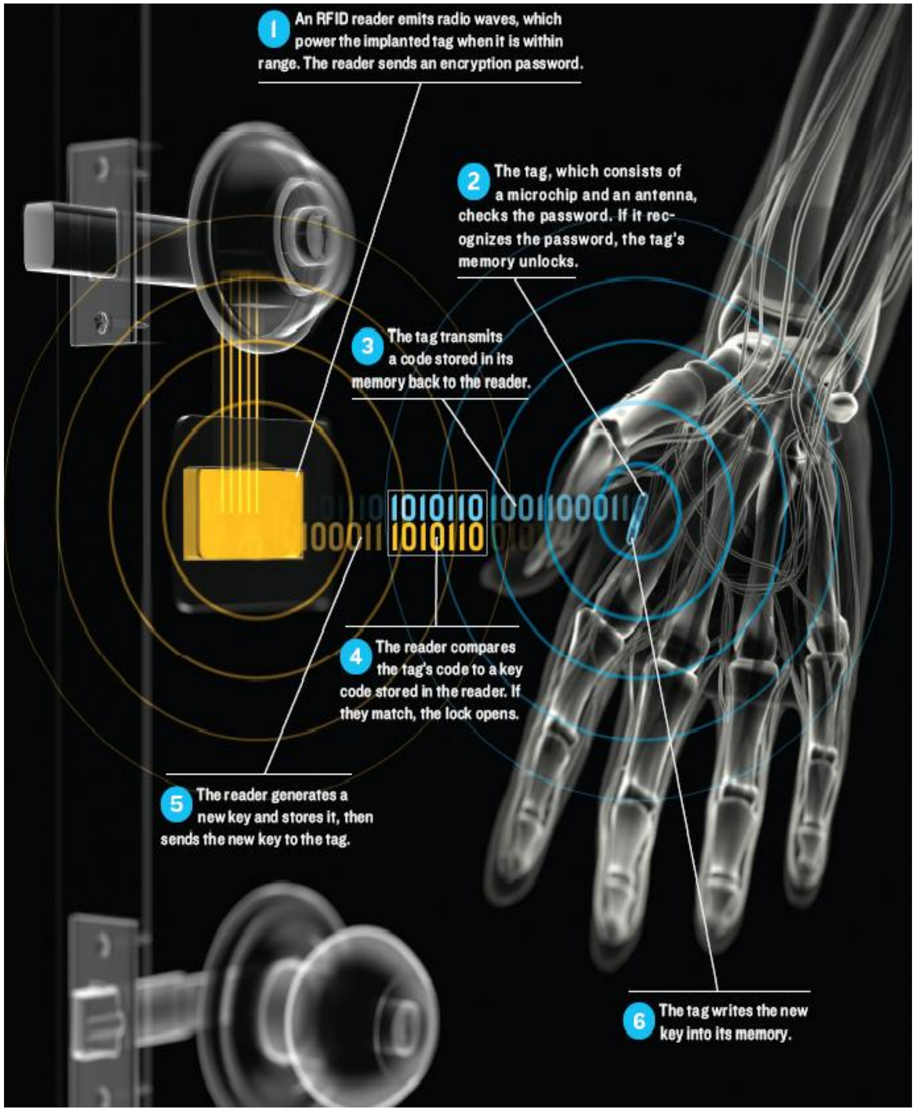
"RFID Inside" and "Hands on RFID", IEEE Spectrum March 2007

Human Implanting

Applications

Convenience & Secure Entrance:

- RFID systems can be used for all the keys at home, work, cars.
- Several remote controls can be handled such as light switches
- Secure entrance can be guaranteed by only allowing "tagged" personnel. The log of the entrances can be hold in the database
- In 2004, general attorney of Mexico had himself and his staff tagged to control entrance of high security areas.



"RFID Inside" and "Hands on RFID", IEEE Spectrum March 2007

Human Implanting

Applications

Personalized Service

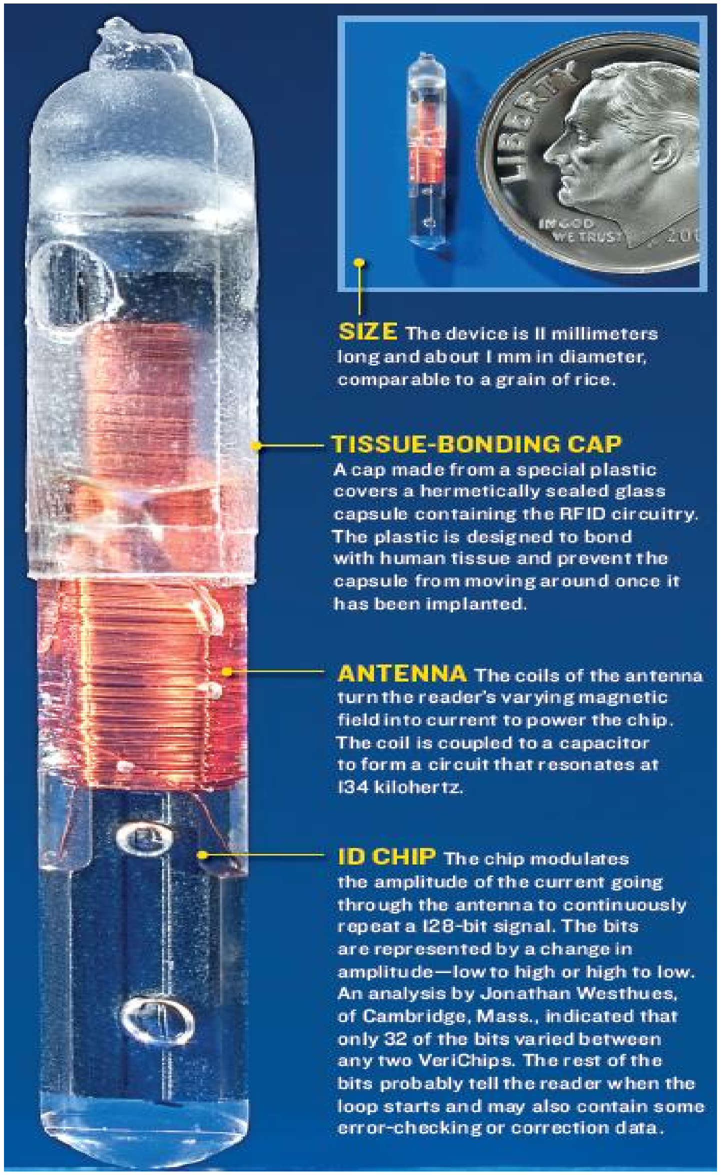
- ❑ **Night clubs in several countries started offering tags to the regular customers**
- ❑ **The cost of the tagging is around $165**
- ❑ **The entrance and all expenses inside can be billed automatically to the customer**
- ❑ **Once inside, the customer is served with his usual preference of drinks, etc.**

“RFID Inside” and “Hands on RFID”, IEEE Spectrum March 2007

RFID Applications: Human Implanting

Technical Aspects : VeriChip

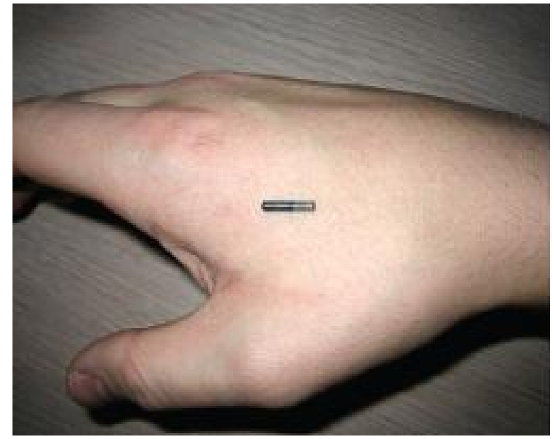
- ❑ **FDA approved the tagging only to the upper arm**
- ❑ **The upper arm location is hard to use with everyday convenience applications**
- ❑ **The read range is 10 cm or less**
- ❑ **Reader cost is expensive (around $600)**
- ❑ **The tissue bonding cap makes it harder to remove**



"RFID Inside" and "Hands on RFID", IEEE Spectrum March 2007

RFID Applications : Human Implanting

Technical Aspects : EM4102



- **Preferred by do-it-yourself tag users**
- **Not produced for human implants, not sterile. User must sterilize it and sign a waiver for implantation**
- **Lacks the tissue bonding coating. Has a glass ampoule coat, easier to remove**

- **Reader is $30 - $50, affordable**
- **Can be implanted to the hand, allowing easy everyday use, opening doors, etc.**
- **Operating Frequency is 125 kHz**
- **Read range is around 5 cm**

"RFID Inside" and "Hands on RFID", IEEE Spectrum March 2007

RFID Applications: Human Implanting

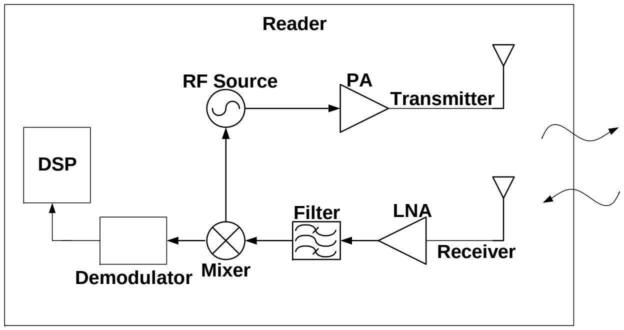
Security Issues

- Security of several RFID's including VeriChip have been challenged
- Researchers showed it was easy to create RFID Cloners that copy the transmitted signal, stealing the ID number
- An encryption technology has been developed that randomly changes the tag's radio signature everytime its read. However, the unique ID remains the same but invisible to copier devices.
- Philips Hitag 2048S tags employ 40 bits of encryption features. The data storage memory is protected and requires a key for access. Every time the tag is used, a new random key is assigned.
- The readers for Hitag chips are expensive ($400) and due to the large number of protocols, the read/write speed is compromised

"RFID Inside" and "Hands on RFID", IEEE Spectrum March 2007

RFID Reader (Interrogator)

- It has a Transmitter and a Receiver, working in a full duplex manner.
- It is the Master unit in the RFID system.
- It is stationary with a continuous supply of power.
- Main Challenges:
  - Power leakage from PA to LNA.
  - Anti-collision procedures.
  - Adjustable transmitted power based on Tag location.
  - Global reader for different standards.



RFID Tags (Transponder)

❑ **Depending on the <u>Power Generation Method</u>, Tags can be:**

- **Passive (battery-less):**
  - **Generate its power from the incoming signal.**
  - **Cheaper**
  - **Short distance of operation.**
  - **Limited processing capability.**

- **Active (has battery):**
  - **Take its power from its associated battery.**
  - **more expensive.**
  - **longer distance of operation.**
  - **better processing capability.**

- **Semi-Passive : (Semi-Active)**
  - **Uses both methods to get its power.**
  - **less expensive (battery lasts longer).**
  - **moderate distance of operation.**
  - **moderate processing capability.**

Types of Tags

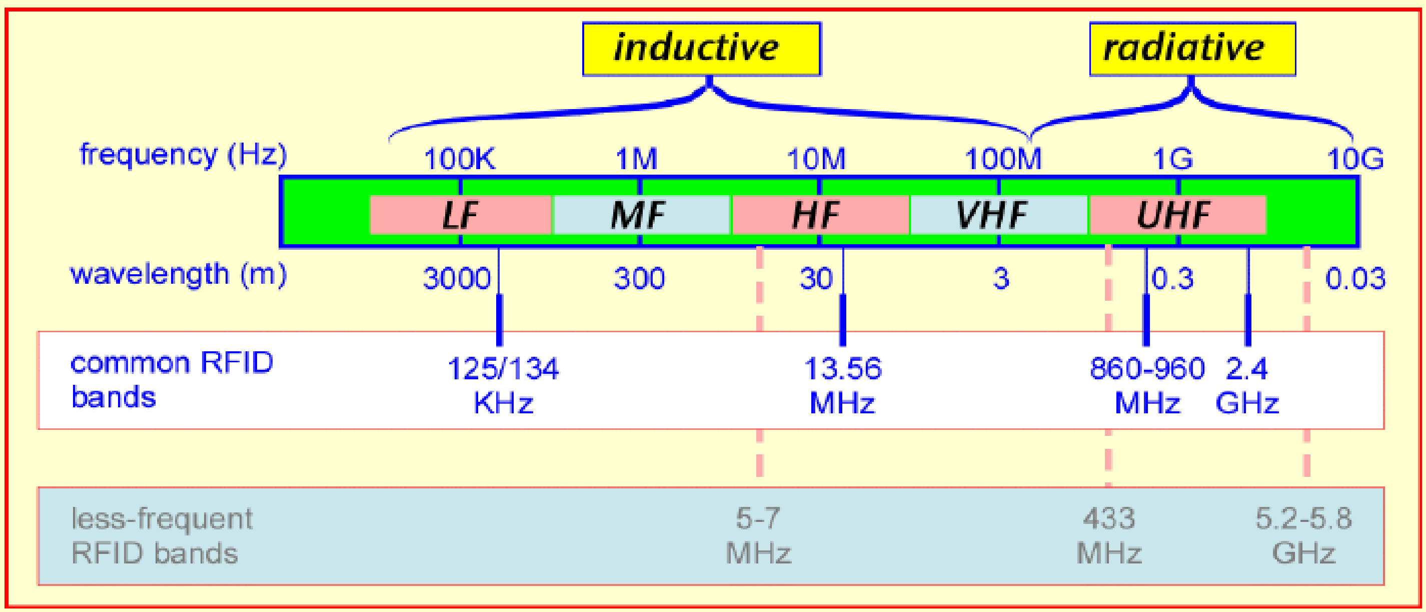
- Depending on the Memory Type, Tags can be:

  - **Read only** - ROM only is used.
    - Cheaper
    - long distance of operation.
    - Limited processing capability.

  - **Read/write:** - ROM + EEPROM.
    - more expensive.
    - short distance of operation (?).
    - better processing capability.
    - Special power generation block is included.

Frequencies of Operation

- RFID systems exist on various frequency ranges.



- Common bands 125 KHz, 13 MHz, 900 MHz, 2.4 GHz
- Frequencies (and wavelengths) vary by over 20,000-fold

Frequencies of Operation

- RFID systems exist on various frequency ranges.

Frequency Tag type:	125 KHz	5-7 MHz	13.56 MHz	303/ 433 MHz	860-960 MHz	2.45 GHz
Passive	ISO 11784/5, 14223 ISO18000-2	ISO10536 iPico DF/iPX	MIFARE (ISO14443) Tag-IT (ISO15693) ISO18000-3		ISO18000-6 EPC class 0 EPC class 1 EPC GEN II Intellitag tolls (Title 21) rail (AAR S918)	ISO18000-4 Intellitag µ-chip
Semi-passive					rail (AAR S918) Intelleflex	ISO18000-4 Alien BAP
Active				Savi (ANSI 371.2) ISO18000-7 RFCode		ISO18000-4 WhereNet (ANSI 371.1)

Standards Overview

- 2.45 GHz RFID Standard ISO/IEC 18000-4

Parameter	Value
Uplink (Reader to Tag)	
Operating Channels	79 Channels from 2422.5 MHz to 2461.5 MHz in 0.5 MHz increment
B.W.	Max of 0.5 MHz
FHSS	Hop rate > 2.5 hops/sec
Modulation	Ask (modulation index = 99%)
Duty Cycle	50 % ± 5 %
Bit rate	30 – 40 kbps
Bit rate accuracy	± 100 ppm (0.01 %)
Backscatter return downlink	
Modulation	Backscatter (OOK)
Duty Cycle	50 % ± 5 %
Bit rate	30 – 40 kbps
Bit rate accuracy	± 15 %

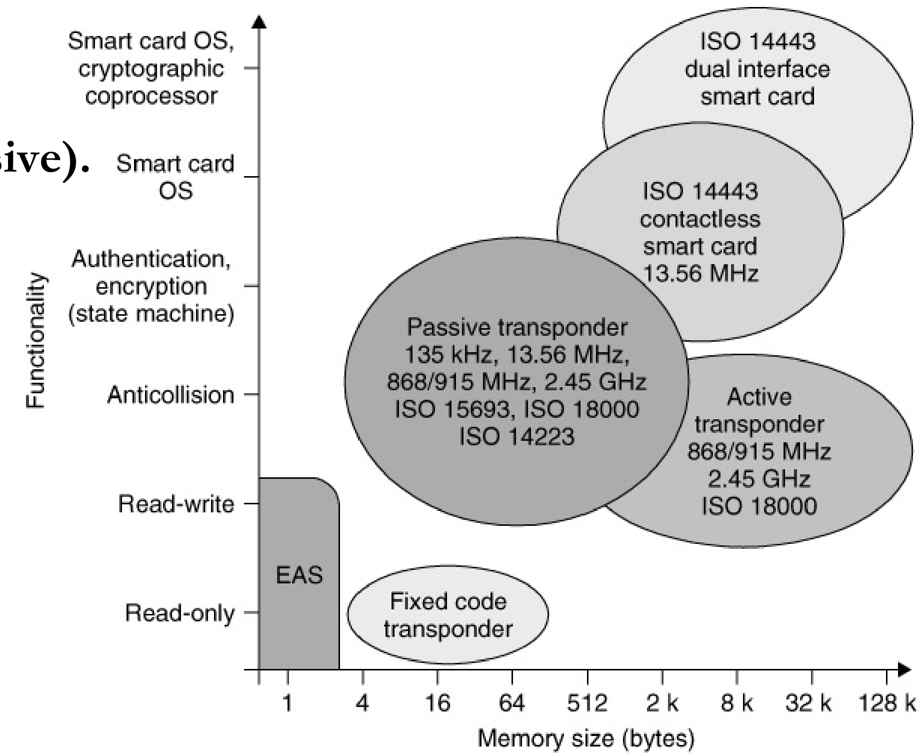
Standards Overview

- 13.56 MHz RFID Standard ISO/IEC 15693

Parameter	Value
Uplink (Reader to Tag)	
Operating Channels	One channel at 13.56 MHz ± 7 KHz
Min/max operating field.	H_{min} = 150 mA/m rms, H_{max} = 5 A/m rms.
Modulation	ASK (modulation index = 10 % and 100 %)
Data coding	PPM (1 out of 256, and 1 out of 4)
Bit rate	1.65 Kbps and 26.48 Kbps.
Backscatter return downlink	
Modulation	Backscatter (mod. amplitude of 10mv when measured as in test methods)
Bit rate	6.62 – 16.69 Kbps.

Application Specific Features

- ❑ Transmission Frequency.
- ❑ Power Generation (Active/Passive).
- ❑ Read/Write Capability.
- ❑ Authorization Control.
- ❑ Transmission range.
- ❑ Data Capacity.
- ❑ Anti-collision procedure.

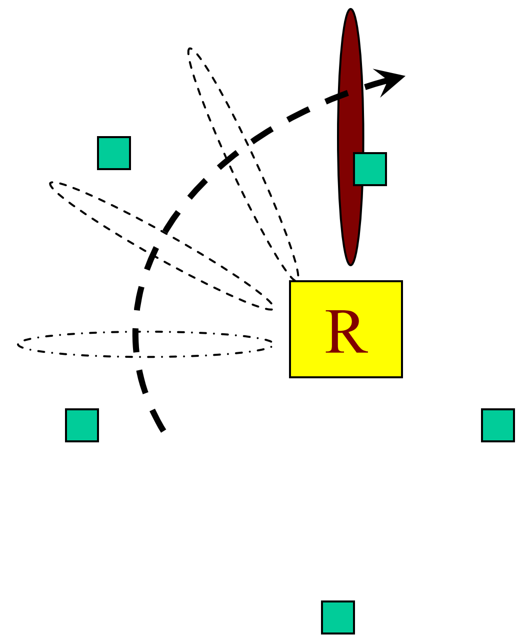


K. Finkenzeller, *RFID Handbook*, 2ND ed., Wiley,West Sussex, England 2003

Anti-Collision Procedure

- Anti-Collision can be done:

  - Time Multiplexing
  - Frequency Multiplexing
  - Space Scanning



System Design (Passive Tag Systems)

- **Step1: Extraction of the design specifications for the target application**
  - **Frequency of operation (range, complexity, and penetrating capability)**
    Antenna directivity (expected direction of the communication link)
    Data rate (amount of data exchanged, and the required on-time)

- **Step2: Calculation of the power budget**

$$P_{incident}\Big|_{dB} = P_{transmitted} * (Propagation\ loss) * (Antenna\ gains) * (Multipath\ loss)$$
$$= P_{dissipated\ in\ the\ antenna} + P_{absorbed\ by\ the\ tag} + P_{reflected}$$

- **Step3: Selection of the uplink modulation scheme (Reader to tag)**

$$SNR = Signal\ level\Big|_{dB} - (noise\ floor + 10\log BW)$$

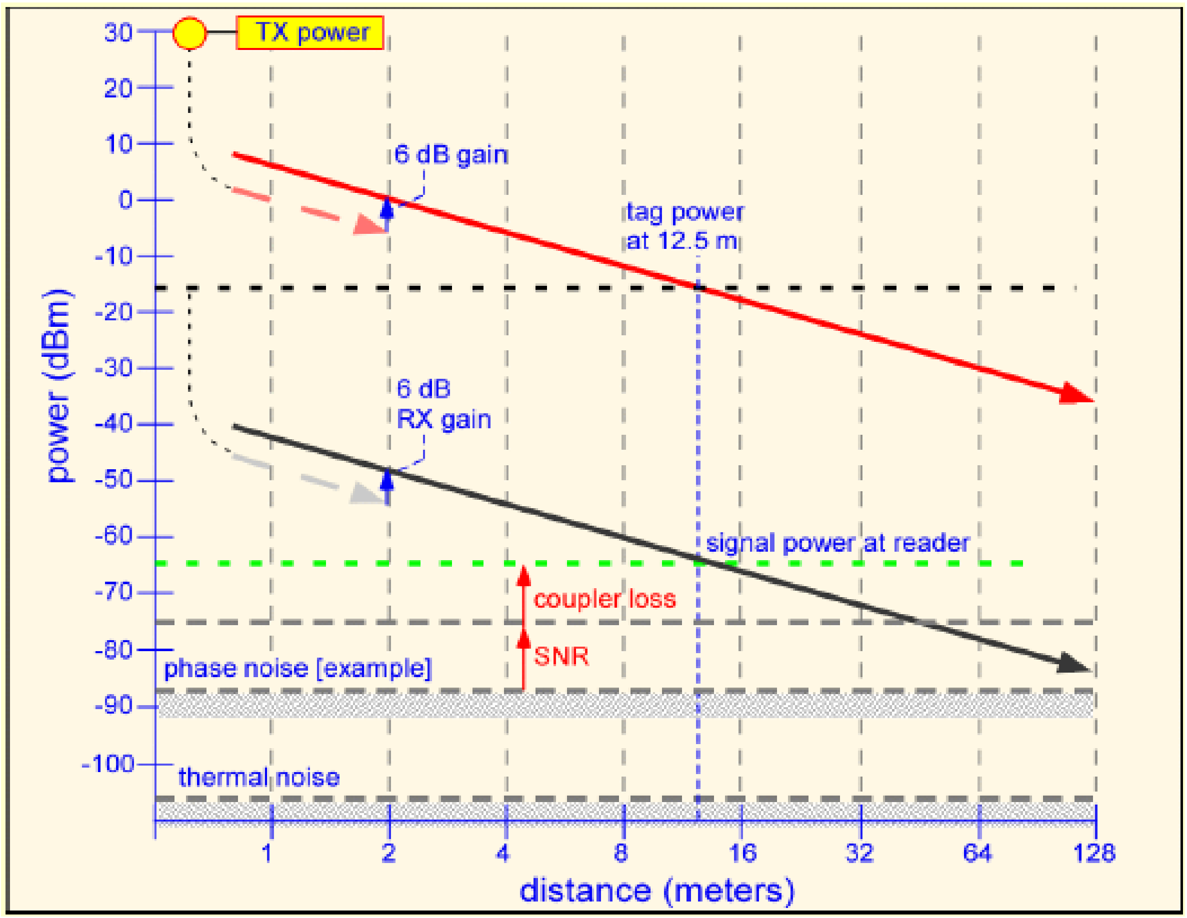
❑ **Step4: Decision on the downlink (tag to reader) modulation scheme**

$$SNR = P_{reflected} - propagation\ loss - (noise\ floor + 10\log BW) - NF\big|_{receiver}$$

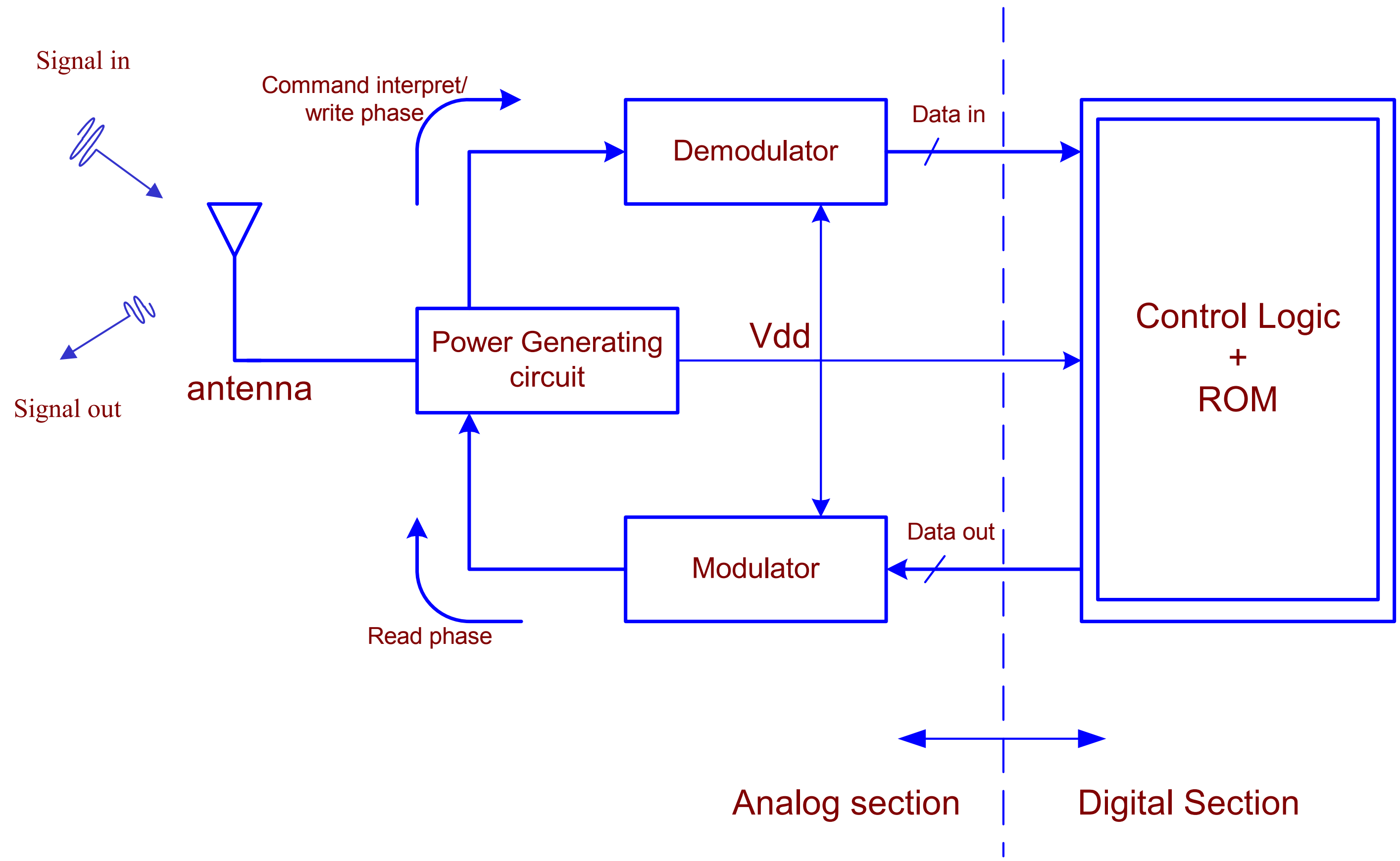
❑ **Step5: Decision on the implementation of the power generation circuit**

$$Power\ generation\ losses = P_{received,average} - P_{reflected,average} - P_{antennna\ loss} - P_{consumed,tag} - Power\ Margin$$

Passive Tag Link Budget



Typical Passive Read-only Tag Structure



Tag Building Blocks

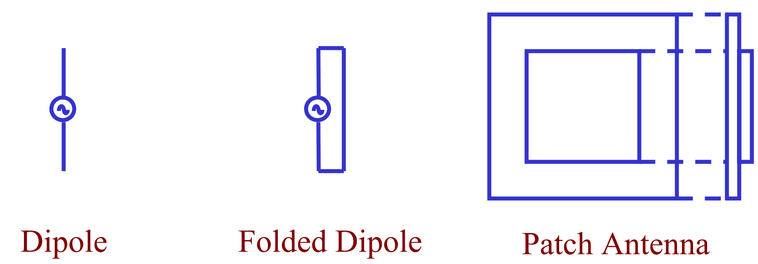
- **Antenna:**

  - **Low Frequency:**
    - Loop antennas.
    - Inductive coupling.
    - Simpler, Cheaper tags.
    - Large antenna size.

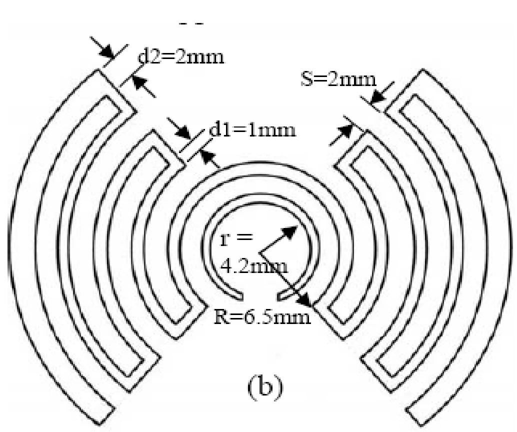
  - **High Frequency:**
    - Electric dipole, folded dipole, printed dipole, printed patch, or log-spiral antennas .
    - Propagation coupling.
    - Complex, expensive.
    - Smaller antenna sizes.

Antenna

Frequency	Transmitting Antenna dimensions
13.56 MHz low reading range (30 cm)	20 cm x 20cm
13.56 MHz low reading range (2 m)	75 cm x 90cm
900 MHz	7.5cm – 15 cm
2.4 GHz	3cm – 6 cm



Antenna [1]



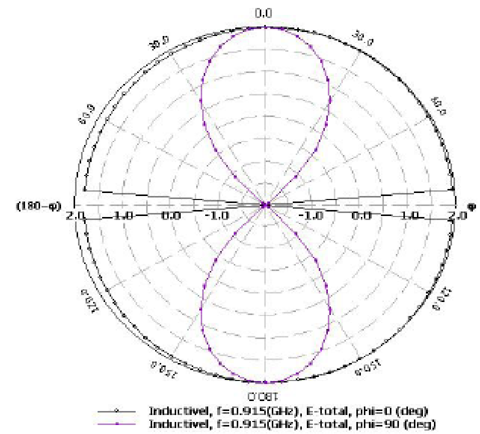


Fig. 5 Radiation pattern display of the antenna with arc-shape arms, directivity=1.99dBi

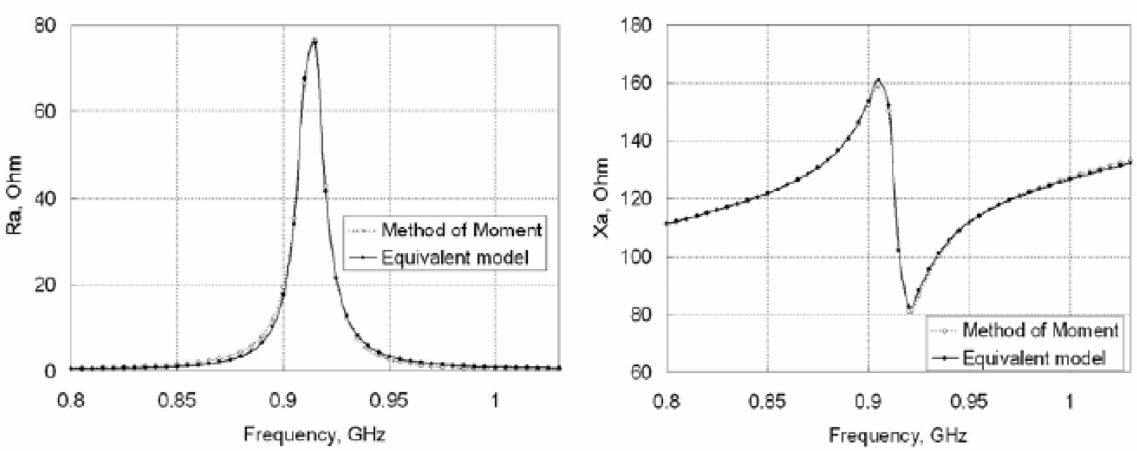


Fig. 4 Antenna impedance against frequency for the arc-shape configuration: (a) Resistance component Ra, (b) Reactance component Xa

Antenna [2]

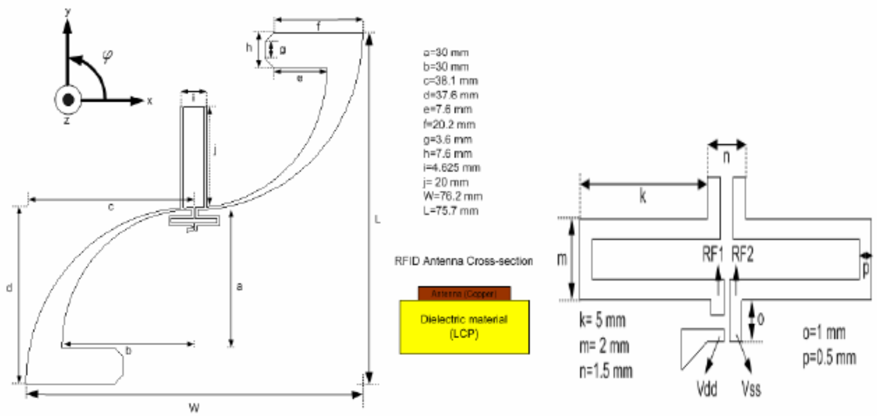


Figure 1. RFID Antenna structure and double inductive stub matching network

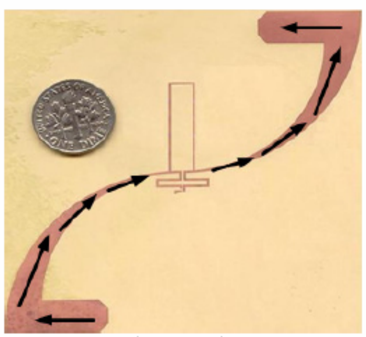


Figure 2. Fabricated RFID antenna and single dipole antenna direction of current flow

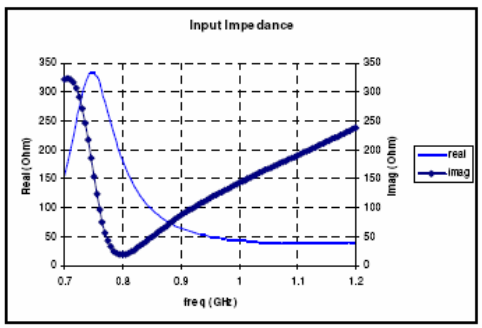


Figure 3. Input impedance of the simulated RFID antenna

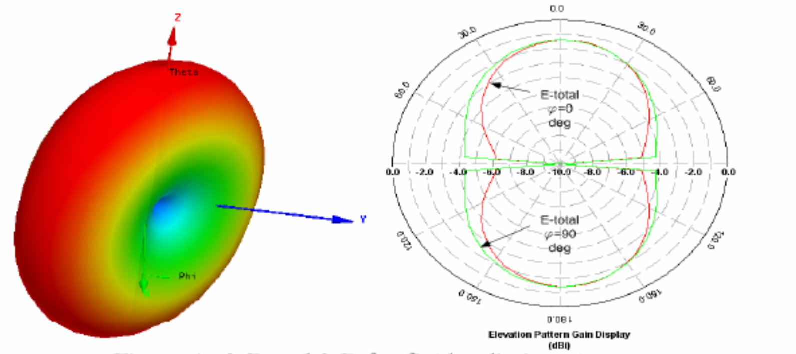
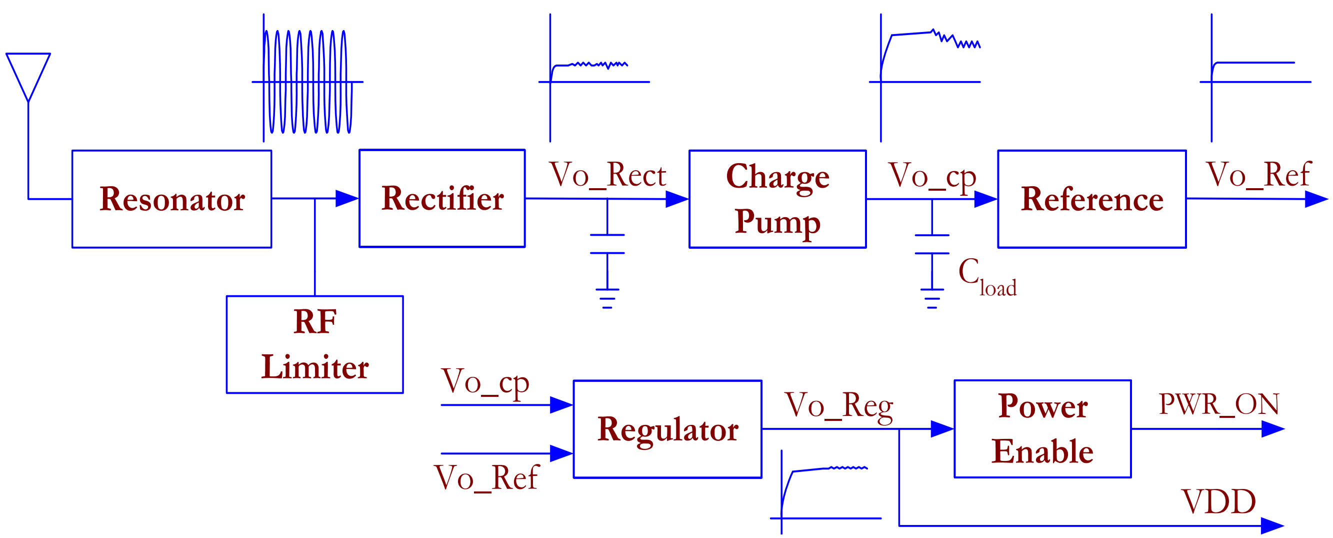


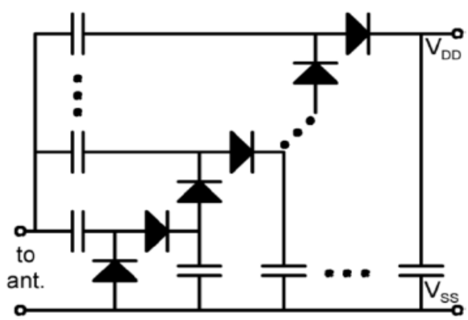
Figure 4. 3-D and 2-D far-field radiation plots.

Tag Building Blocks

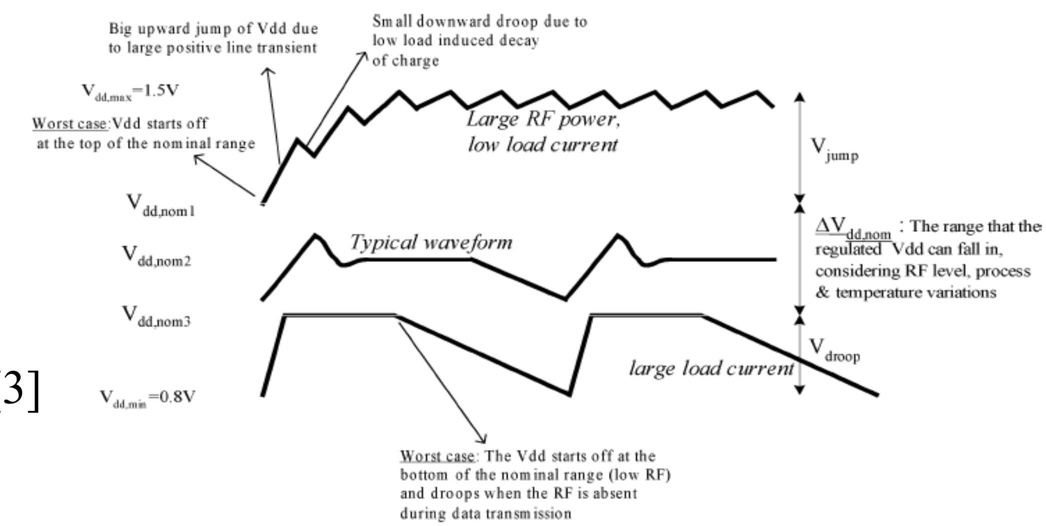
- **Power Generating Circuit:**
  - **It makes use of RF-DC conversion and subsequent voltage regulation to obtain the desired stable power supply.**
  - **Performance is affected by the choice of the downlink and uplink modulation schemes.**



Power Generating Circuit



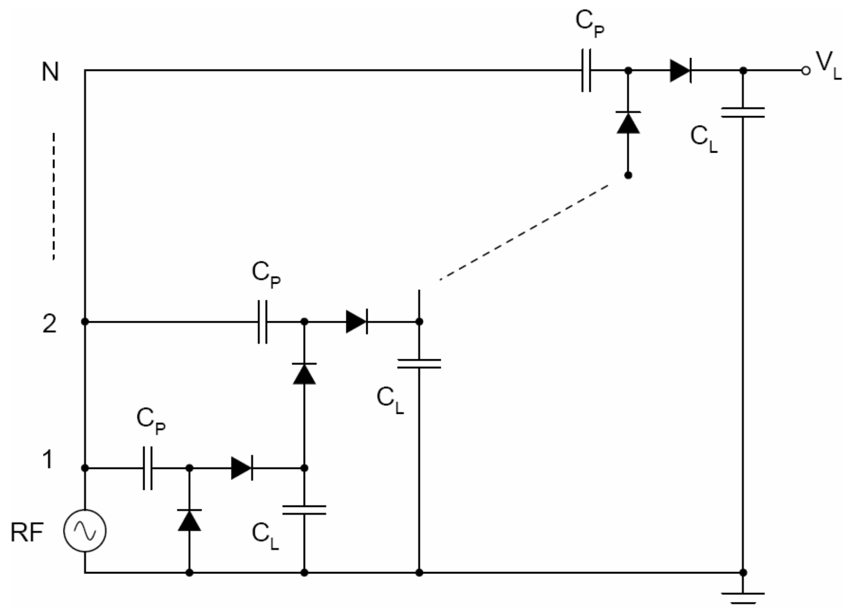
Basic Voltage multiplier Circuit [3]



Typical Vdd variations [4]

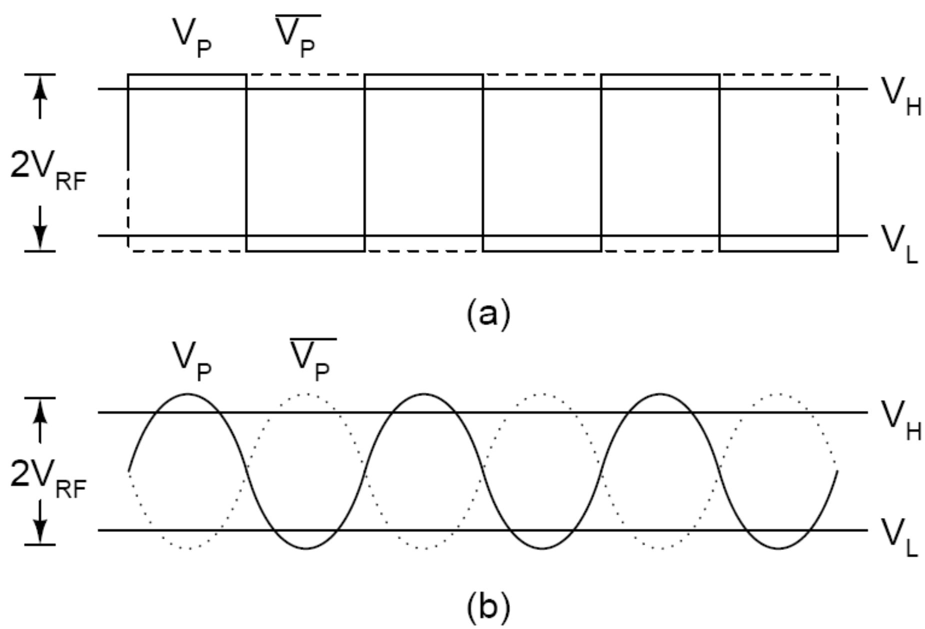
Schottky Based Rectifiers [5]

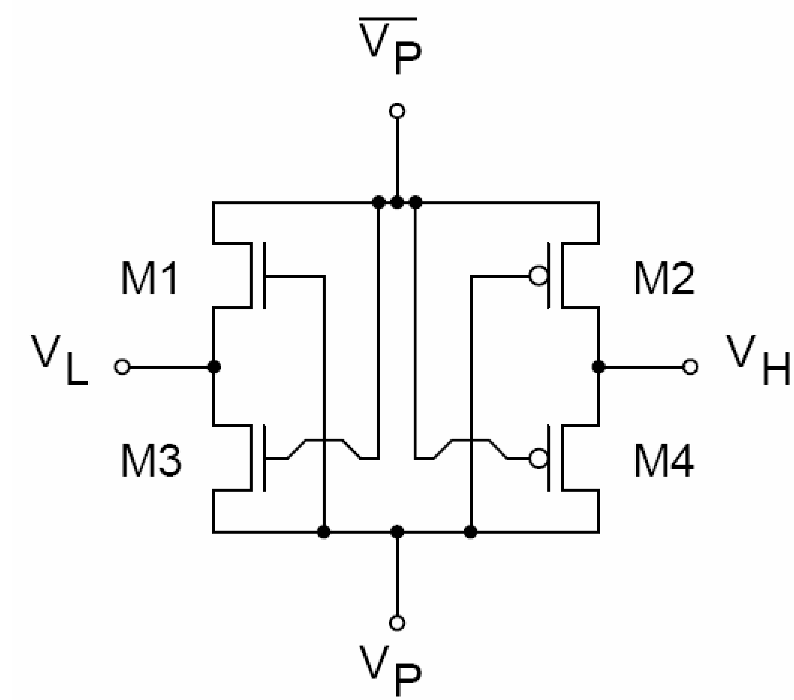
- $V_L = 2N (V_{in} - V_{th})$
- **Each doubler stage produces a DC voltage $2(V_{in} - V_{th})$.**
- **Schottky diodes with low values of V_{th} are used.**



The Four Transistor Cell [5]

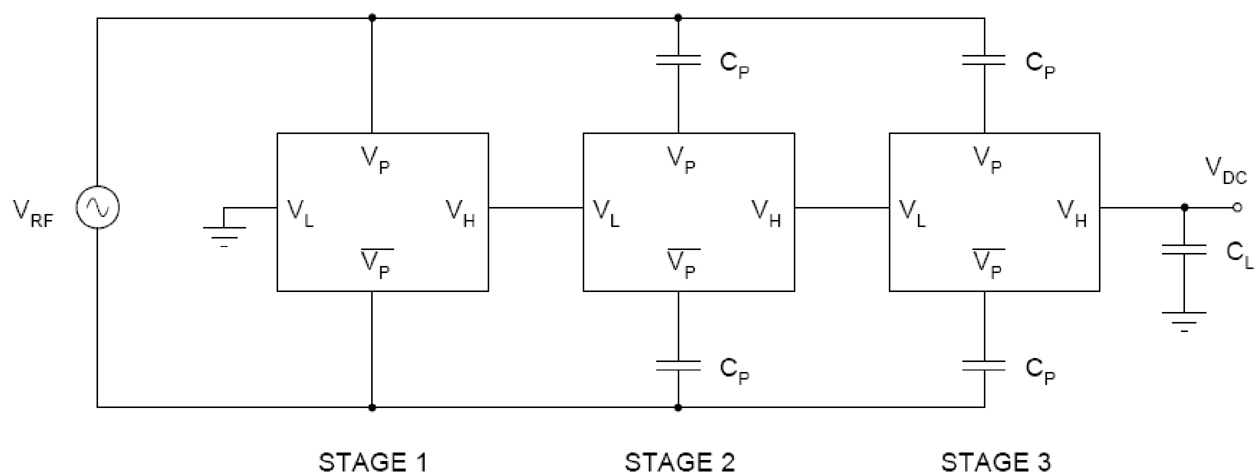
- $V_{DC} = (V_H - V_L) = (2V_{RF} - V_{drop})$
- V_{drop} represents losses due to switch resistance and reverse conduction.
- V_{drop} increases as the load current I_L increases and V_{RF} decreases.





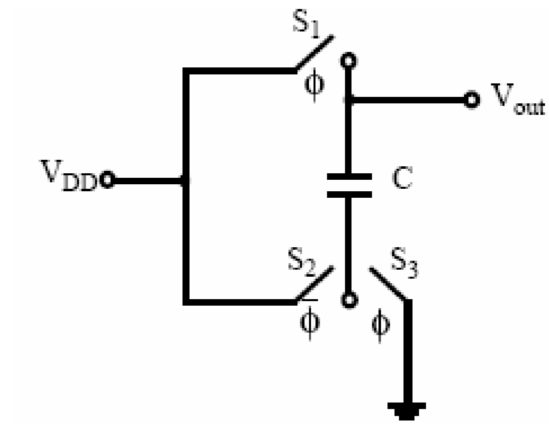
Cascading Rectifier Cells [5]

- The input RF signal V_{RF} is assumed to be purely differential (no defined common mode voltage, circuit startup issues).
- Succeeding stages are capacitively coupled to V_{RF} through C_P, allowing V_{DC} to build up at the output.
- Thus the circuit behaves as a charge pump voltage multiplier.
- Expected output $V_{DC} = N(2V_{RF} - V_{drop})$.
- Practically, V_{DC} is generally lower than expected because V_{drop} is not constant and increases down the cascade of cells due to body bias effects.

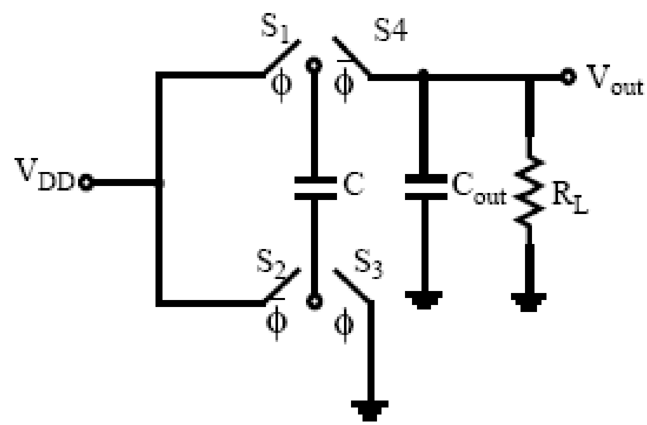


Charge Pump: Voltage Doubler [6]

- **Simple voltage doubler**
  $(V_{out} - V_{DD})\ C = V_{DD}\ C$
  $V_{out} = 2V_{DD}$

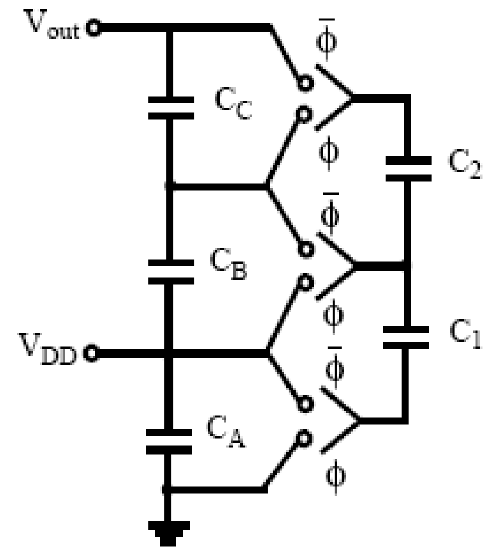


- **Practical voltage doubler**
  $V_{out} = 2V_{DD} \times C/(C + C_{out})$



Cockcroft-Walton Voltage Multiplier [6]

- Voltage multiplication greater than twice the supply voltage can be achieved by cascading more than one capacitor in series.
- During phase Ø, C_1 is connected to C_A and charged to V_{DD}.
- During Ǿ, C_1 will share its charge with C_B and both charged to $V_{DD}/2$ if they have equal capacity.
- In the next cycle, C_2 and C_B will be connected and share a potential of $V_{DD}/4$ while C_1 is once again charged to V_{DD}.
- If this process continues for a few cycles, charge will be transferred to all the capacitors until a potential of $3V_{DD}$ is developed across V_{out}.



Dickson Charge Pump [6]

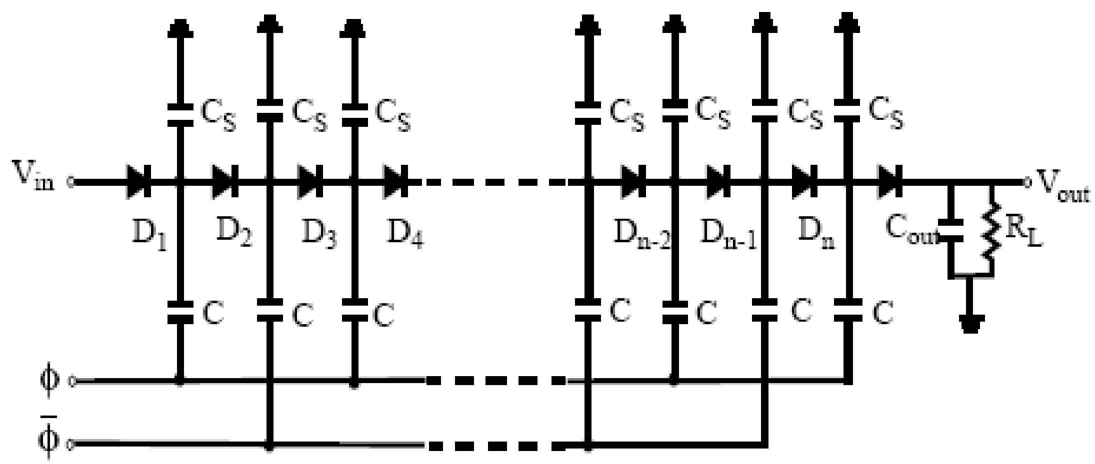
$$V_{out} = V_{in} + N \cdot (V_{\phi} - V_d) - V_d$$

- **Taking the stray capacitance C_s into account**

$$V_{out} = V_{in} + N \cdot \left(\left(\frac{C}{C + C_s}\right) \cdot V_{\phi} - V_d\right) - V_d$$

- **In the presence a load that draws a current I_{out}**

$$V_{out} = V_{in} + N \cdot \left(\frac{C}{C + C_s} \cdot V_{\phi} - V_d - \frac{I_{out}}{(C + C_s) \cdot f_{osc}}\right) - V_d$$



Dickson Charge Pump [7]

- CMOS Implementation

$$V_{out} = V_{in} + N \cdot \left(\frac{C}{C+C_s} \cdot V_\phi - V_{tn} - \frac{I_{out}}{(C+C_s) \cdot f_{osc}} \right) - V_{tn}$$

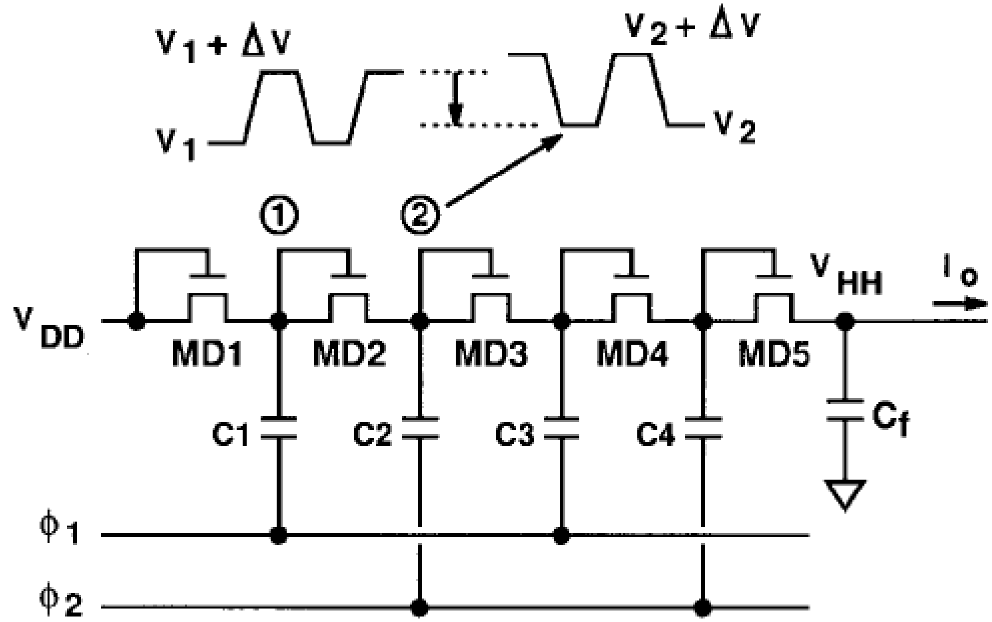
- The voltage fluctuation at each pumping node (the voltage change that occurs at each node from one clock cycle to the next): ΔV

$$\Delta V = \frac{C}{C+C_s} \cdot V_\phi - \frac{I_{out}}{(C+C_s) \cdot f_{osc}}$$

- The voltage pumping gain of a charge pump: G_V

$$G_V = V_N - V_{N-1}$$

$$G_V = \Delta V - V_{tn}$$



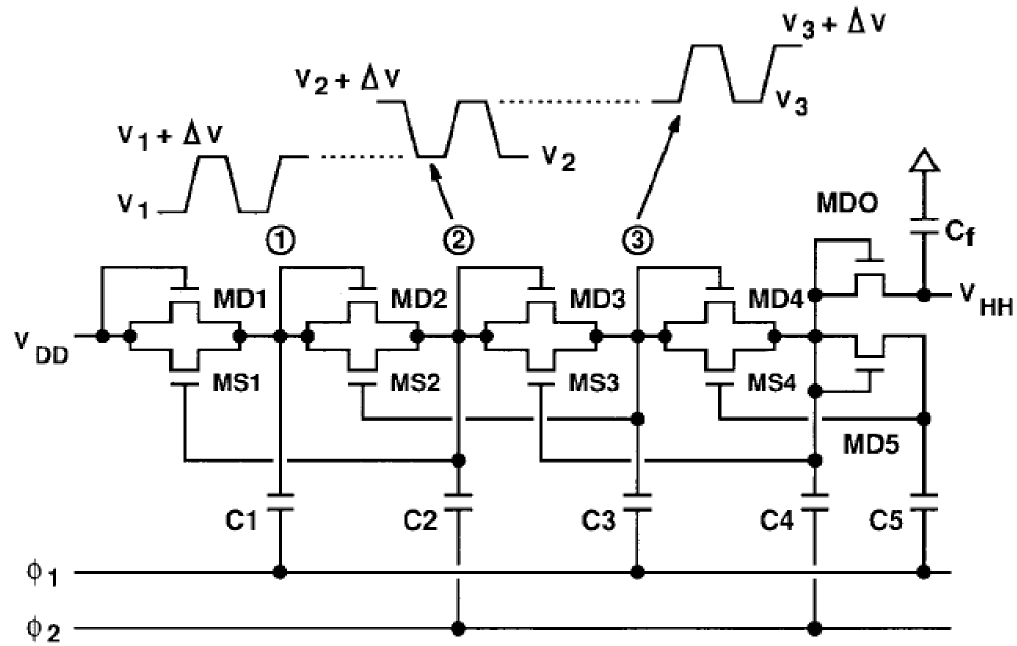
Static CTS Charge Pump [7]

- **NCP-1**

$$G_V = G_{V2} = V_2 - V_1 = \Delta V.$$

$$2\Delta V > V_{tn}(V_2)$$

$$2\Delta V < V_{tn}(V_1)$$



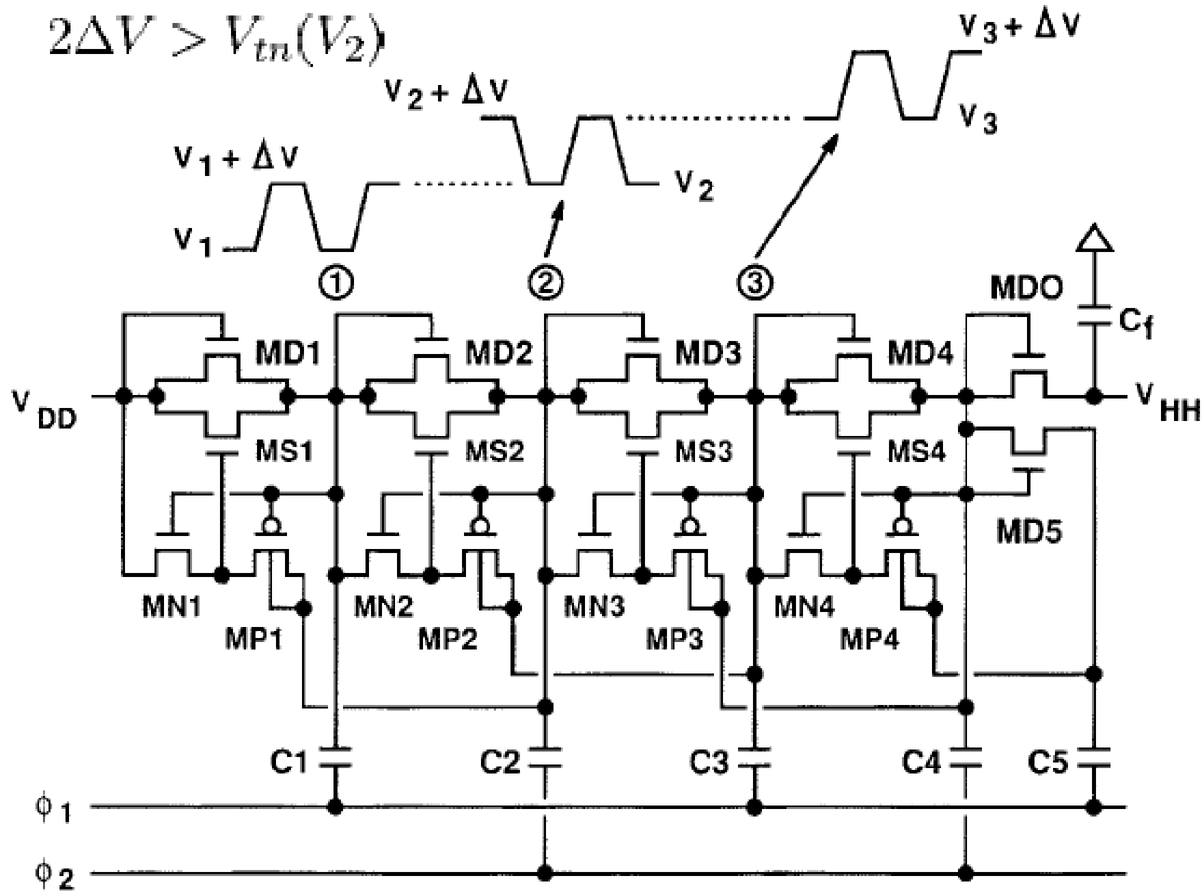
$$\mathrm{Max}(G_{V2} + G_{V3}) = \mathrm{Max}(V_3 - V_1) = V_{tn}(V_1)$$

Dynamic CTS Charge Pump [7]

- **NCP-2**

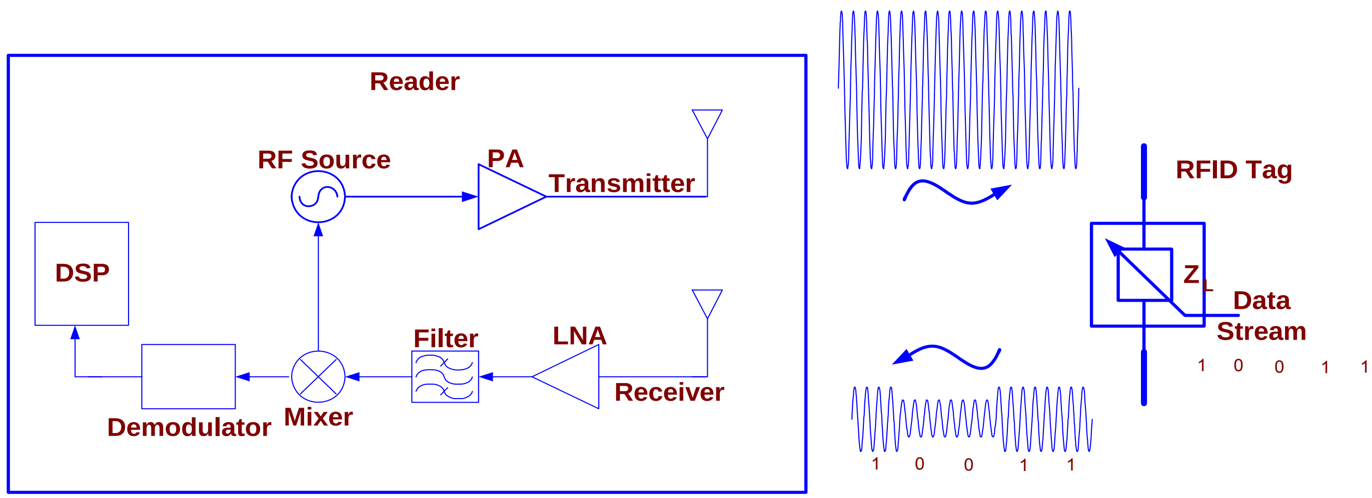
$2\Delta V > V_{tp}$ and $2\Delta V > V_{tn}(V_2)$

$2\Delta V > V_{tn}(V_1)$



Tag Building Blocks

- Modulator (Downlink Modulation):
  - A modulation scheme with a low-power implementation is required.
  - Changing the input impedance of the tag antenna changes the amplitude, or phase of the back-scattered signal introducing *Backscatter Modulation*.



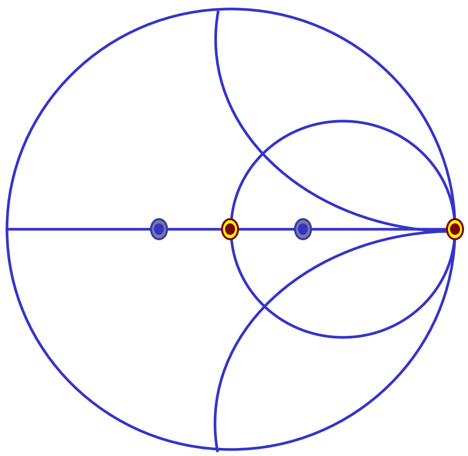
Backscatter Modulation

- **By modulating the real part of the input impedance, keeping the imaginary part matched.**

$$Z_1 = R_1 - jX_{ant} \quad or \quad Z_2 = R_2 - jX_{ant}$$

$$\rho \; is \; pure \; real \; < 1$$

$$S_{reflected} = \rho_{in} \; S_{incident}$$ **ASK-Modulation**

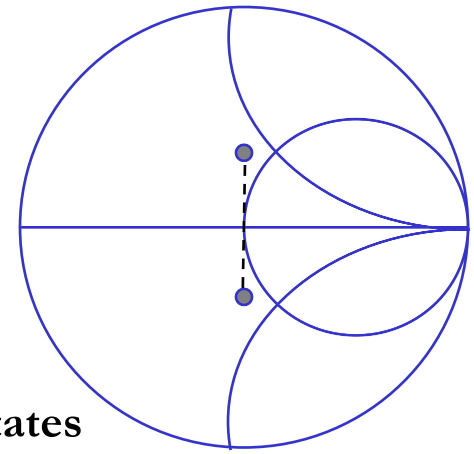


$\rho_1 = 0, \rho_2 = 1$ **ON-OFF Keying**

$\rho_1 = m, \rho_2 = -m$ **Symmetric, with equal mismatch amounts**
Where, m is defined to be the modulation index

Backscatter Modulation

- **By modulating the imaginary part of the input impedance, keeping the real part matched.**



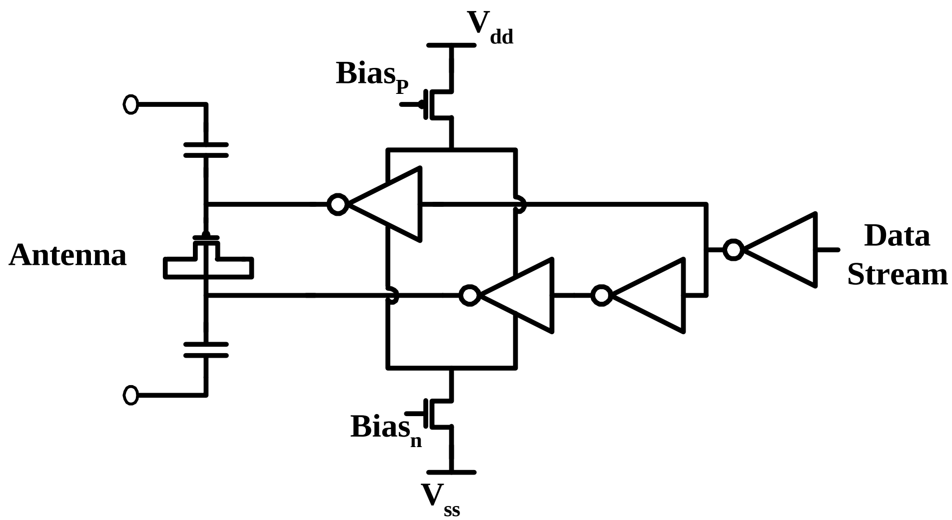
$$\rho \text{ is pure imaginary} \quad Z_1 = R_{ant} + jX_1 \ \text{ or } \ Z_2 = R_{ant} + jX_2$$

$$S_{reflected} = \rho_{in} \ S_{incident}$$ **PSK-Modulation**

- $\rho_1 = jm, \rho_2 = -jm$ **Equal amount of mismatch in both states**

Modulation Technique	*Power absorbed by the tag*	*Power back scattered to the interrogator*	*Power dissipated in the antenna*
ASK (On-Off Keying)	$\frac{P_{avail}}{2}$	$\frac{P_{avail}}{4}$	$\frac{P_{avail}}{4}$
PSK BM ($\pm m$)	$(1-m^2)*P_{avail}$	$m^2 * P_{avail}$	0
ASK BM ($\pm m$)	$\frac{1-m^4}{(1+m)^2} P_{avail}$	$m^2 * P_{avail}$	$\frac{2m(1-m)}{(m+1)} P_{avail}$

Backscatter Modulation [3]

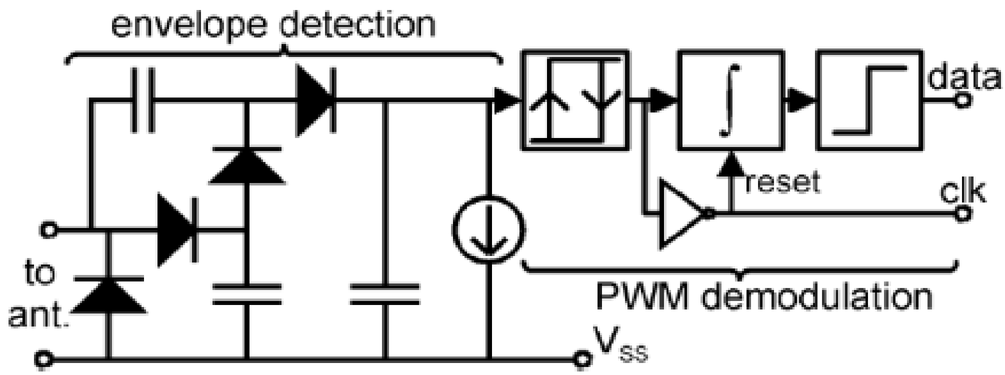


- Modulates the input capacitance of the antenna.
- Suitable at high frequencies or capacitor multiplier should be used.

Tag Building Blocks

- **Demodulator (Uplink Modulation):**
  - **Random data sequence should not affect the power received by the tag.**
  - **Clock recovery scheme should be included.**
  - **Coding scheme for proper clock recovery (Manchester, …).**
  - **ASK, PWM or FSK can be used.**

Demodulator



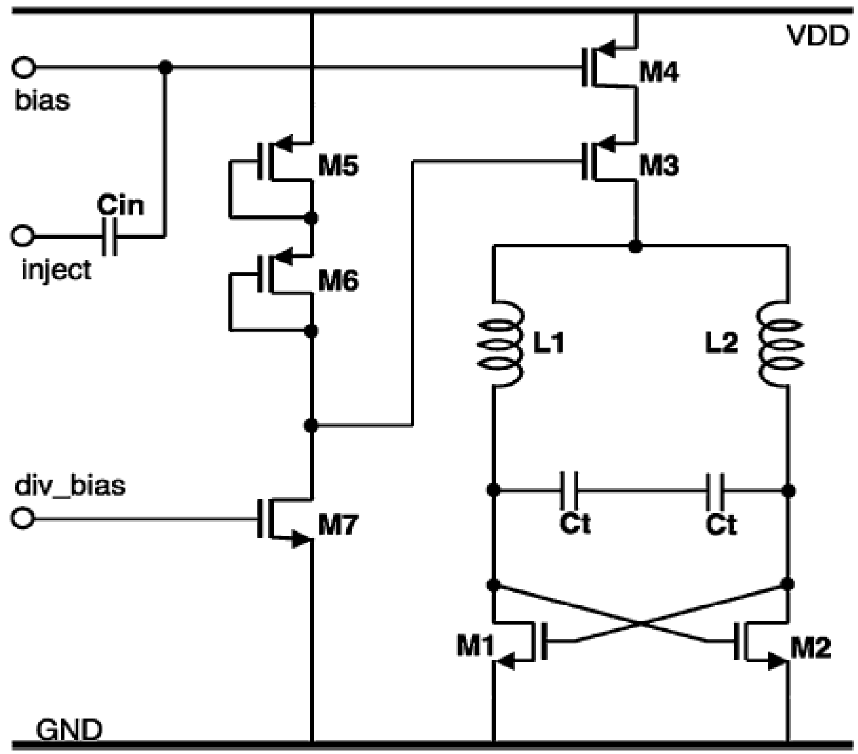
- **Example of PWM demodulator and clock recovery [3].**
- **Envelope detector + Schmitt trigger + integrator + comparator.**

Tag Building Blocks

- Carrier Recovery:

  - Carrier recovery can be done using injection locking oscillator.

  - Locking can be to a specific harmonic, frequency isolation can be achieved.



Tag Building Blocks

- Clock Recovery:
  - Can be extracted from carrier by division (if carrier exists).
  - It can exist inherently in the modulation Scheme (PPM, PWM, …).
  - Encoding can be used at the interrogator side for clock information and better detection (Manchester, …).

Design Example – AMSC RFID

Parameter	*Specification*
Technology	0.35 um CMOS
RF input frequency	13.56 MHz
Uplink Modulation Scheme	PWM
Downlink Modulation Scheme	ASK-BM
RF input power	< 0.4 mW
Generated Power Supply	1.2 V
Data Rate	100 kbps
Charging time	150 us
Area	0.64 mm^2

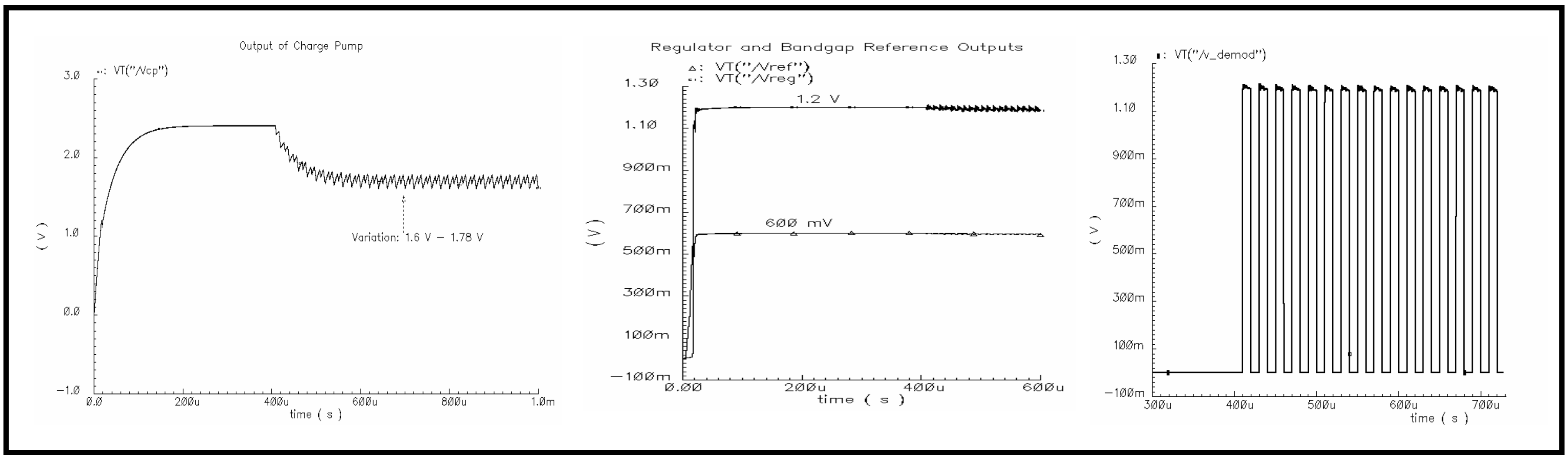
Design Example – AMSC RFID

For a stream of 010101010…

(a) Charge pump output.

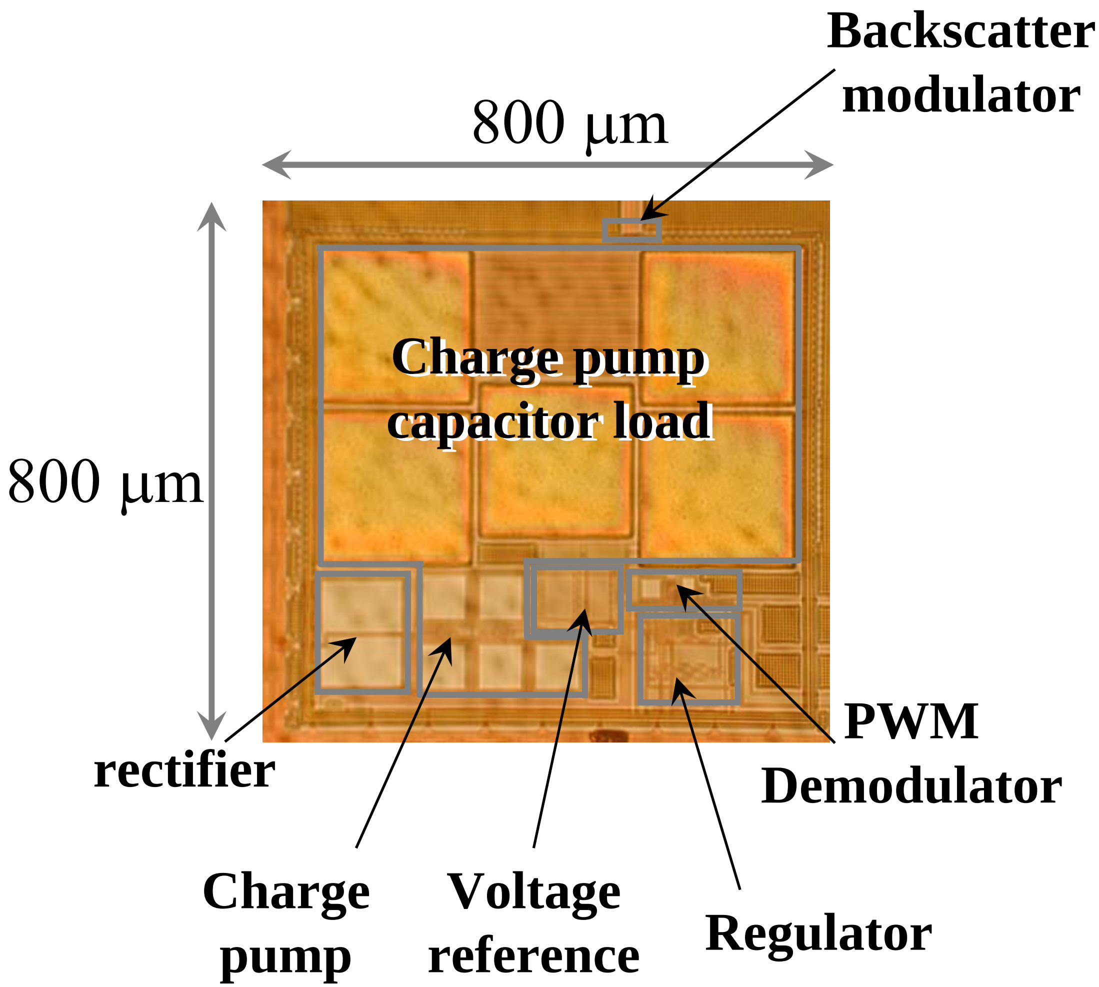
(b) Regulator, Voltage reference output

(c) Output Data stream of demodulator



(a) (b) (c)

Design Example – AMSC RFID

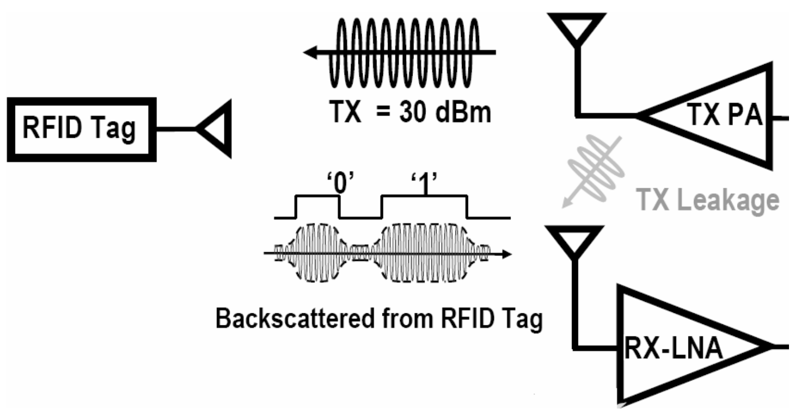


Recent Research Areas

- **Interrogator Level:**
  - ❑ **Leakage from Tx to Rx [9,10]**

Challenge: Receiving weak tag signal in presence of strong Tx blocker

Current Solutions:
- Highly linear front end
- Direct Conversion Rx + DC offset cancellation
- Blocker rejecting LNA
- Changing Gain/Attenuation modes

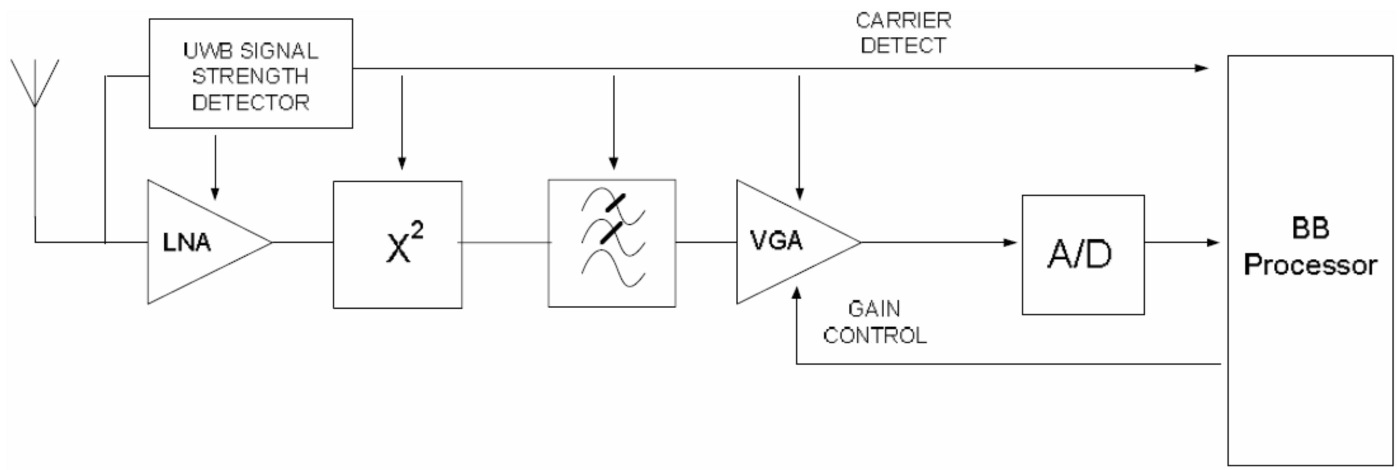


Recent Research Areas

- **Interrogator Level:**
  - **UWB-Impulse Radio for RFID [11]**

Aim: Increasing bitrate in RFID systems

Current Solutions:
- Non Coherent UWB Rx
- SNR must exceed certain threshold
- This occurs at short distances due to limited power

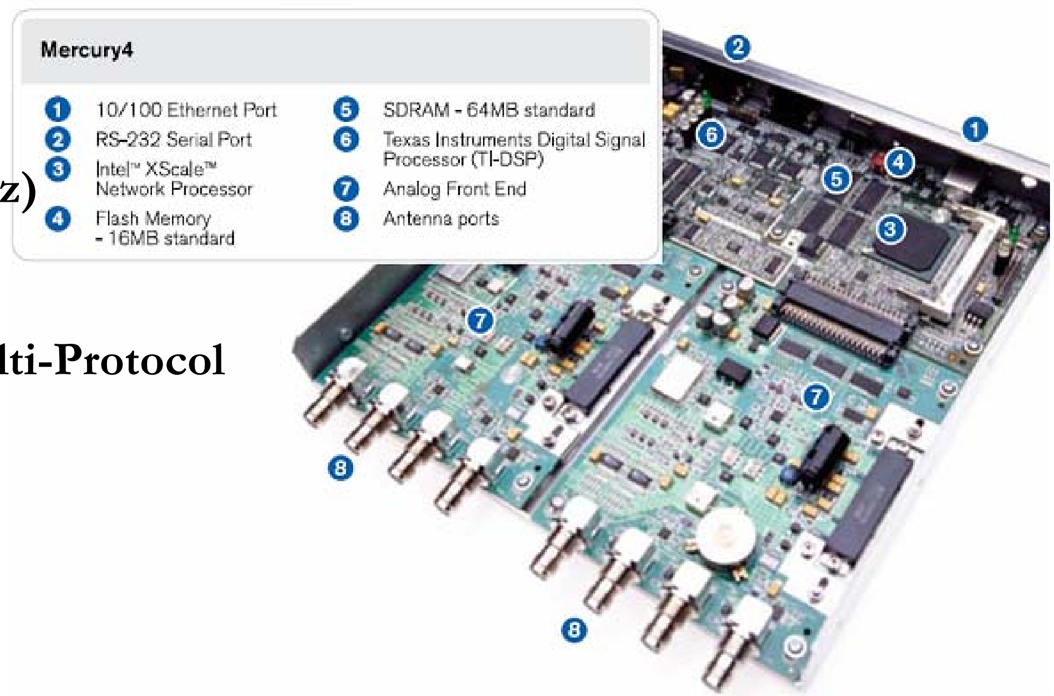


Recent Research Areas

- **Interrogator Level:**
  - ❑ **Reconfigurable reader for multi-standard operation**

    Product: Mercury4 [12]
    (902 – 928MHz),(865 – 868MHz)

    Top level approach:
    “A Dynamic Retargettable Multi-Protocol RFID Reader/Writer”
    University of Tokyo [13]



Future Research Areas

- **Transponder Level:**
  - **Regulator: High performance regulators with low power consumption.**
  - **Clock Divider & Extraction: Get the required clock for the RF signal.**
  - **Charge Pump: Minimize the losses and area.**
  - **Organic Transponders [14]**

Summary

- **RFID uses Radio waves for *contact-less* identification and authentication for a large variaety of applications**

- **Tags can be Passive, Active, or Semi-Passive.**

- **RFID spans wide range of frequencies, frequency of operation emphasizes antenna design trade off's and operation range.**

- **Backscatter modulation scheme is used in the downlink transmission, for minimum power consumption. Different BM schemes have power, area and charge pump efficiency trade-offs.**

- **Uplink modulation scheme could be PWM or ASK with encoding, duty cycle and charge pump performance are traded for PWM. High SNR minimizes BER concerns, emphasis is on complexity and power.**

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