ESD.290

Special Topics in Supply Chain Management

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History

- 1998: DISC founded
- 1999: Auto-ID Center founded Auto-ID Field Trial started 2000
- 2001: First standards presented
- 2002: Gillette orders 500,000,000 tags from Alien
- 2003: Wal-Mart, DoD Mandates

  EPCglobal launched, Center retired
- 2004: More mandates

Outline

- RFID and the Auto-ID Center
- An in-depth look at some issues

Outline, Part I

- RFID and the Auto-ID Center
  - What and why of RFID
  - The cost issue
  - Manufacturing low-cost RFID
  - Handling the data
  - Current status
- An in-depth look at some issues

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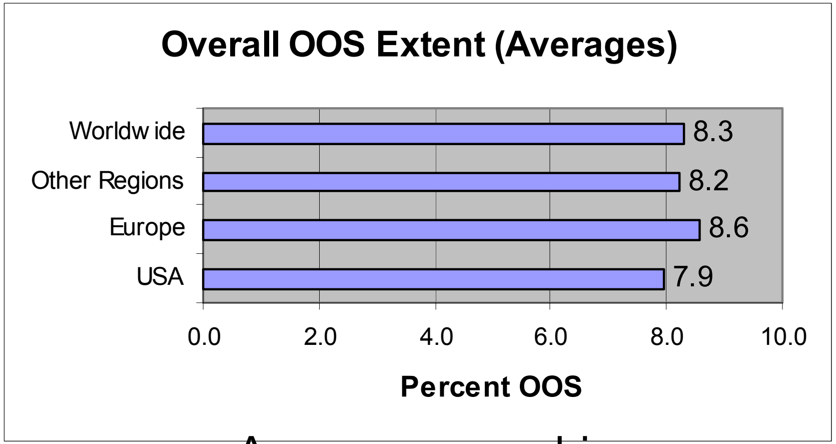
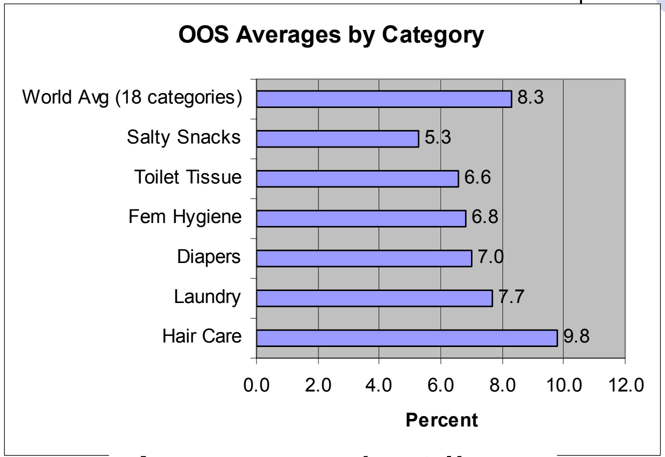
Magnitude of Challenges

- **Inventory Management:**
  - **Inventory uncertainty:**
    - 65 % of 370,000 records inaccurate (HBS study of one major retailer)
    - Transportation uncertainty: Perfect delivery is dismal
  - **Stock-outs:**
    - Average 9% out of stock in retailers world-wide
    - Lost sales due to stock-outs: 4%
  - **Overstock: Huge channel inventories**
    - CPG average 11 weeks inventory
    - Retailers average 7 weeks inventory
    - Locked up capital, industry-wide
- **Brand Management:**
  - Counterfeit:
    - $500B pharmaceuticals business, $50B counterfeit
  - Diversion:
    - Market size difficult to estimate

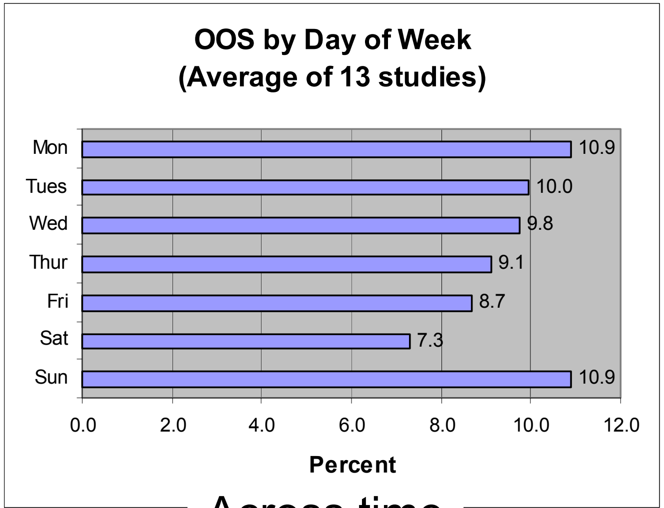
The problems are everywhere



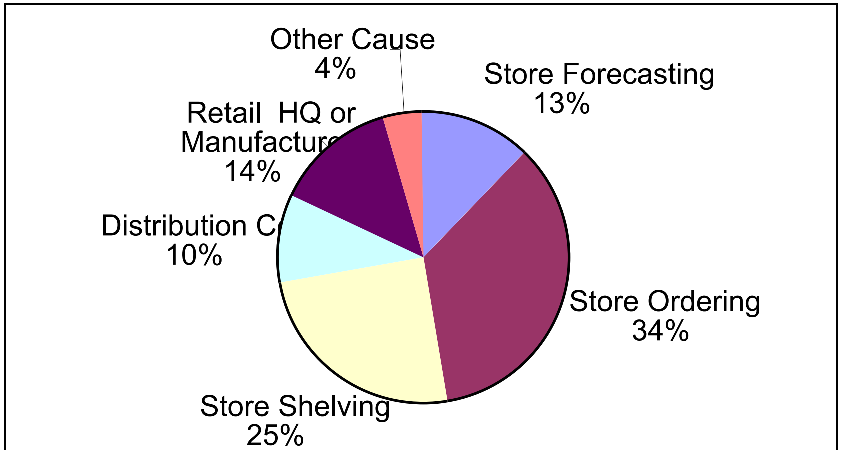
Across geographies



Across product lines

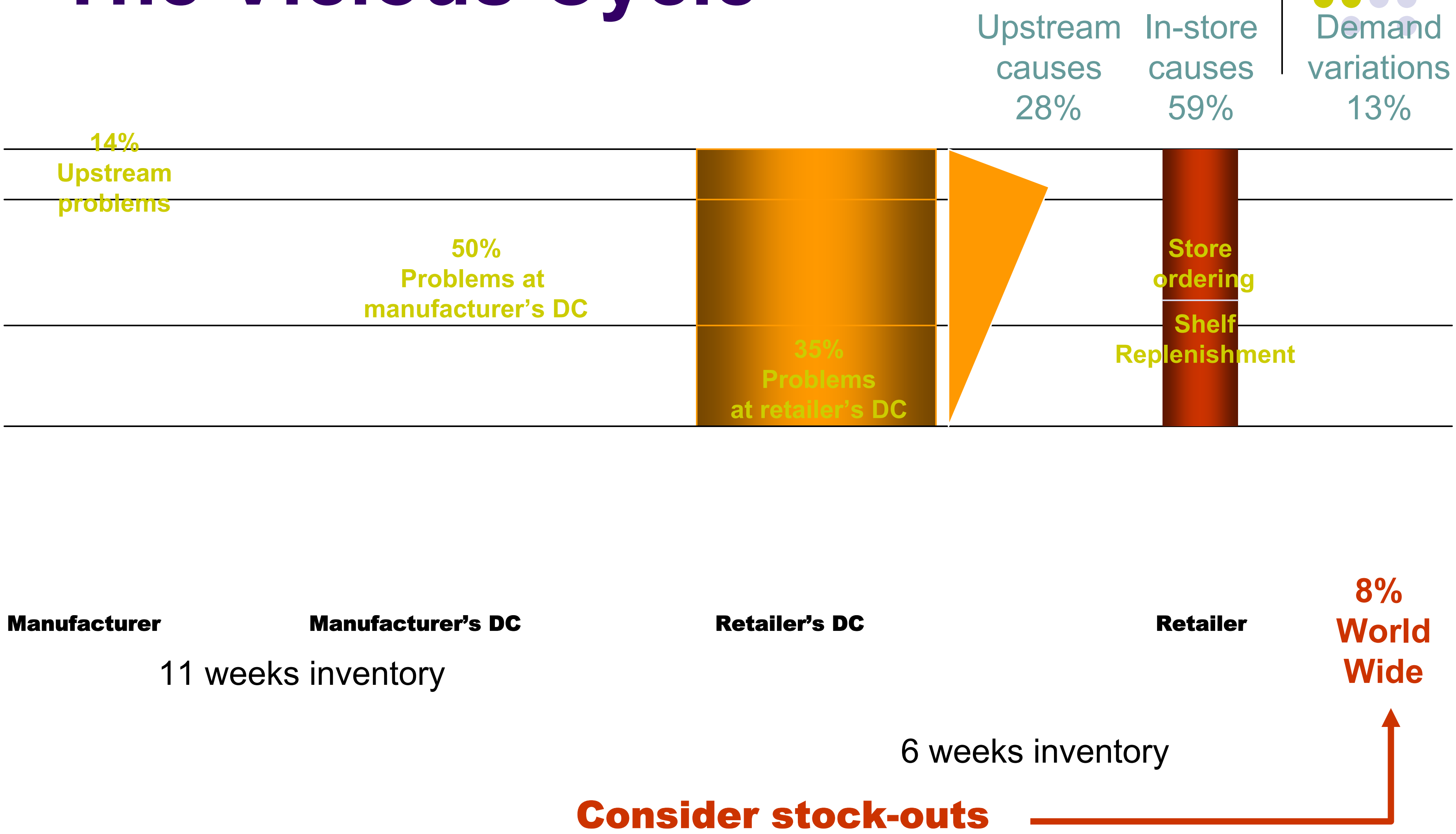


Across time

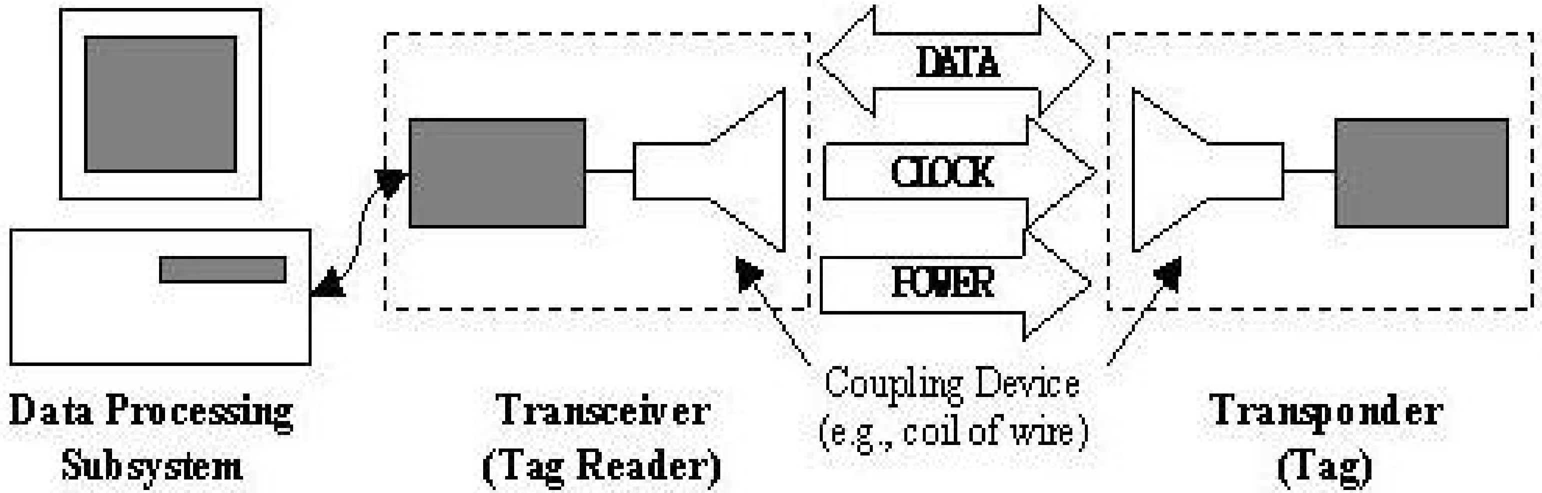


Across the supply chain

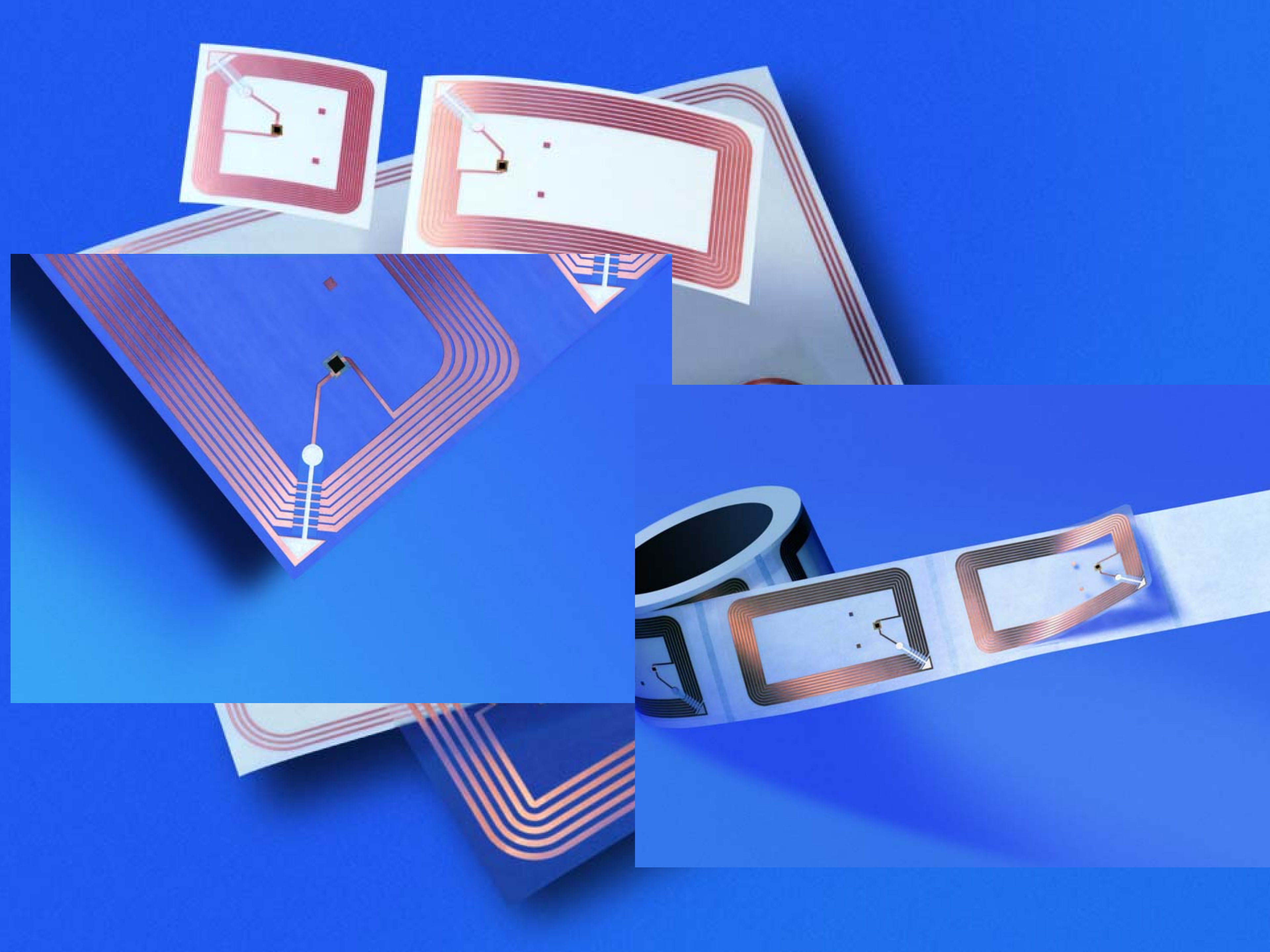
The Vicious Cycle



RFID System

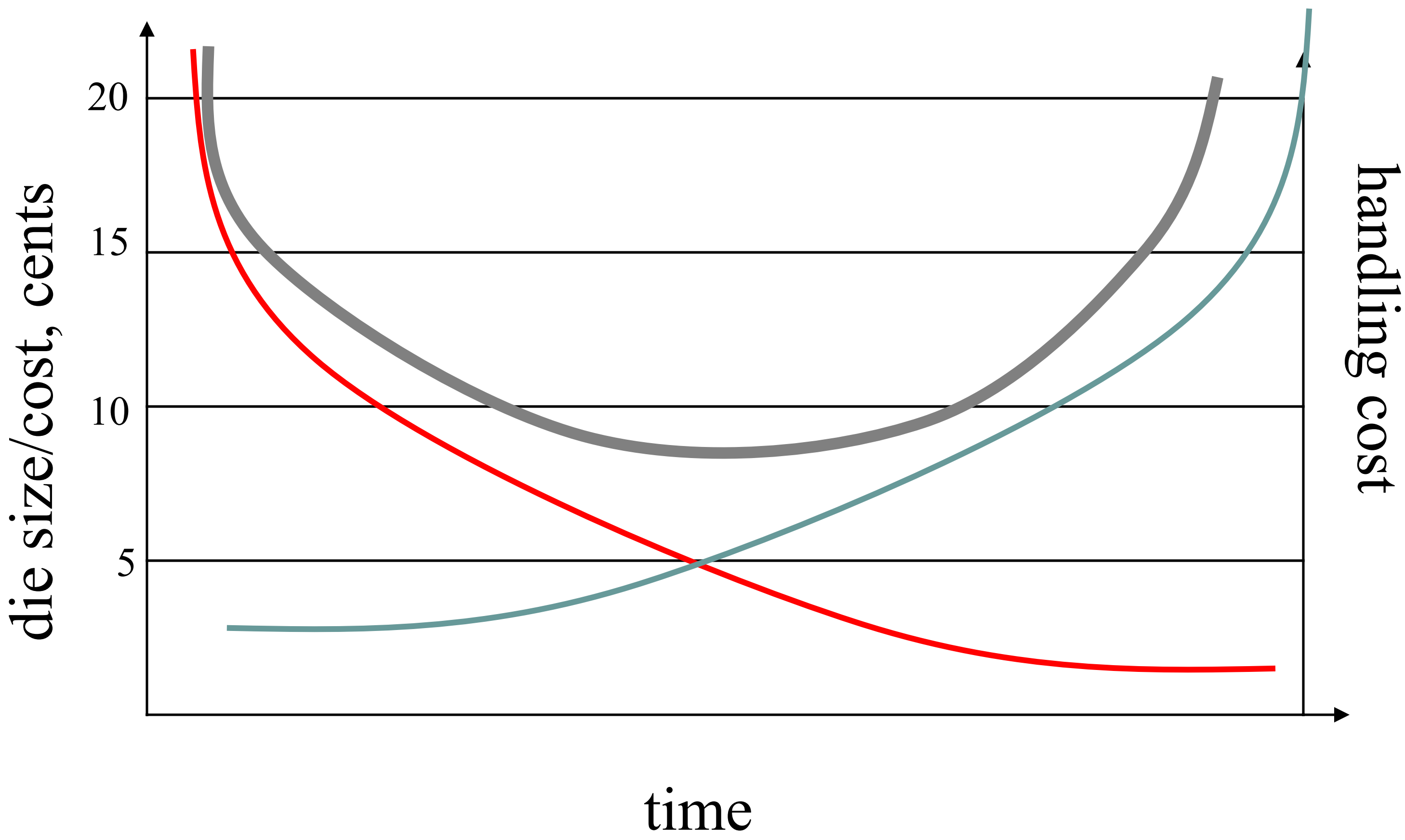


DATA
CLOCK
POWER
Data Processing Subsystem
Transceiver (Tag Reader)
Coupling Device (e.g., coil of wire)
Transponder (Tag)

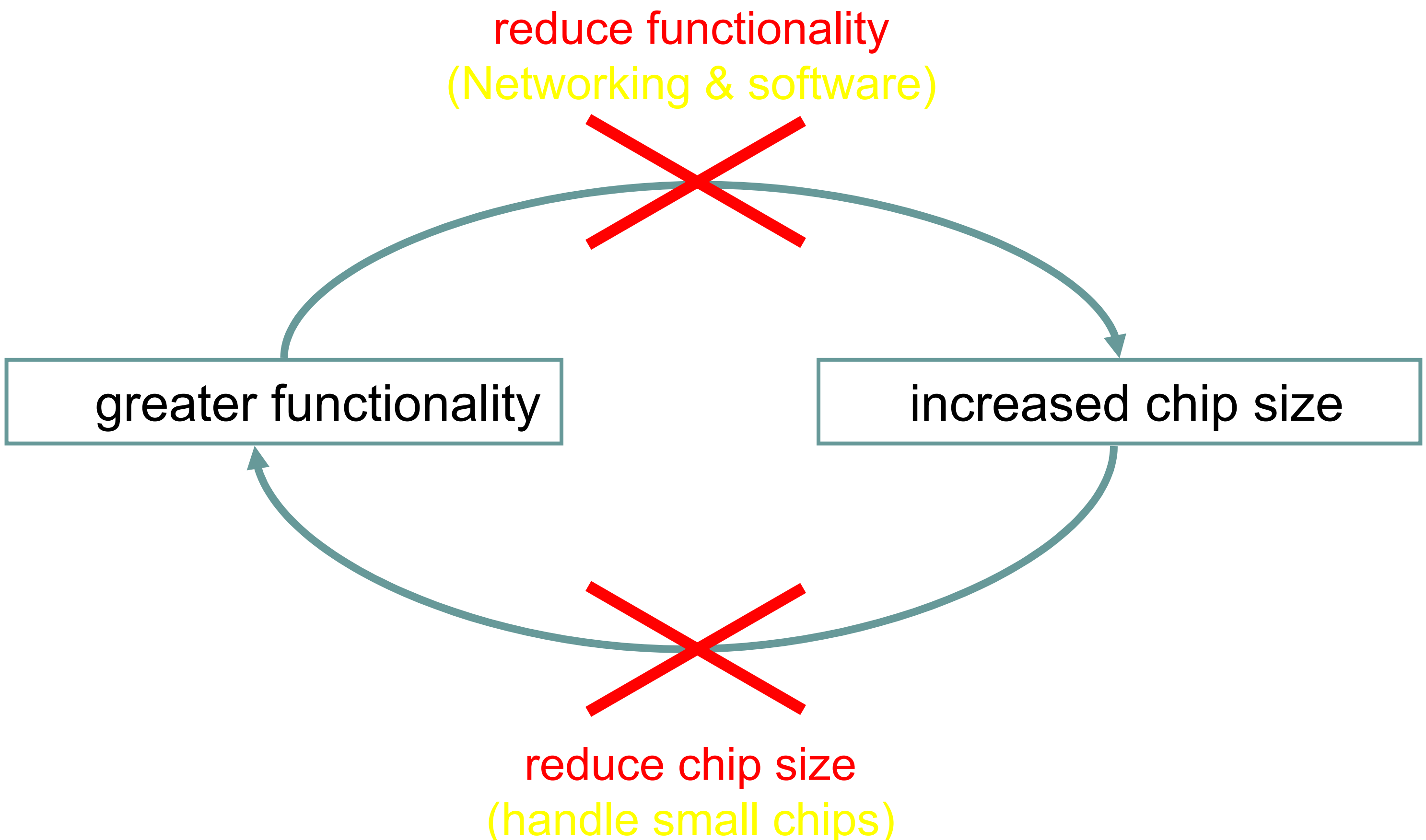


Low cost rfid

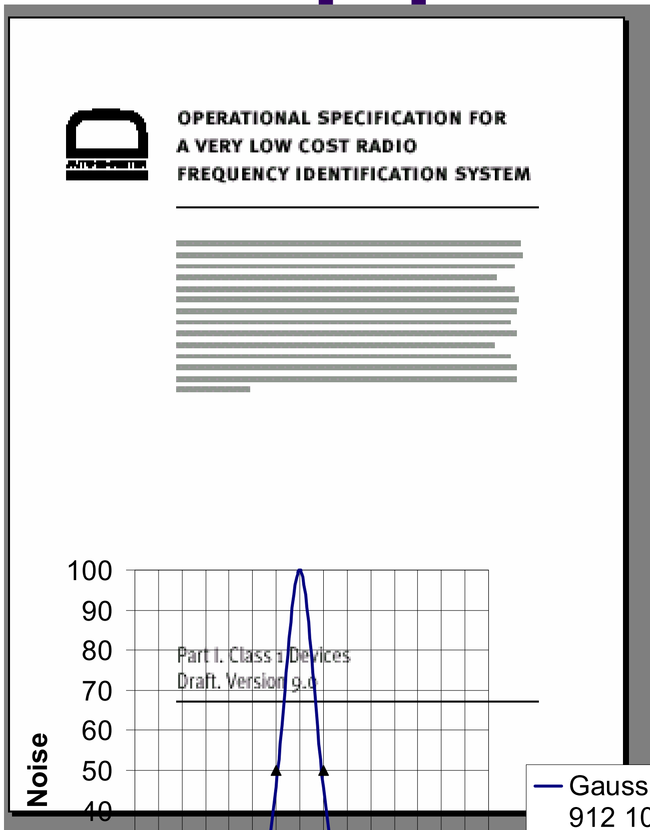
Silicon: 4c/mm^2

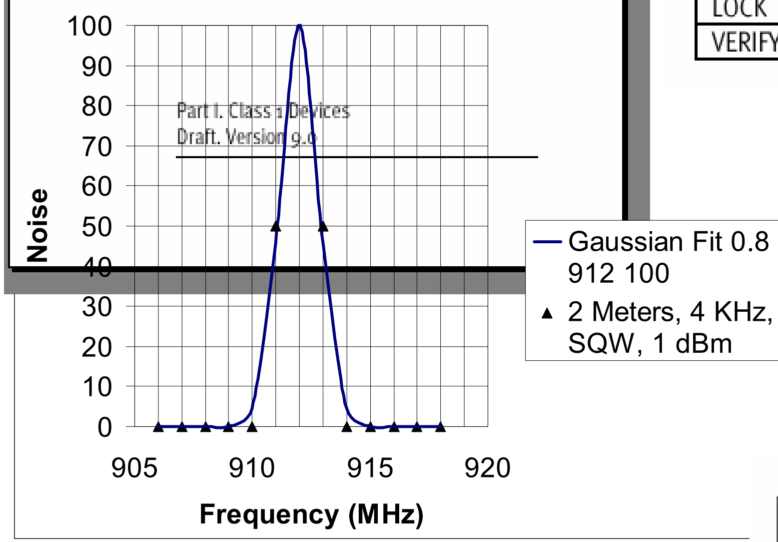


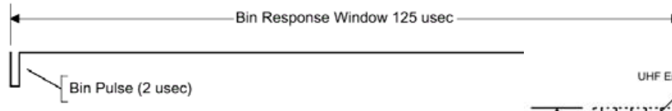
Why is RFID expensive today?

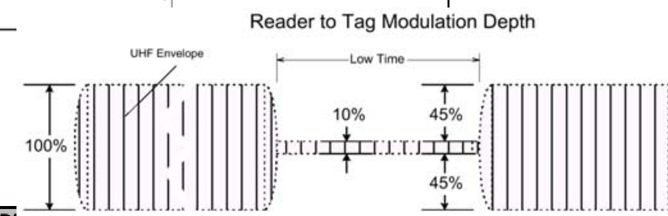


Cheap protocol

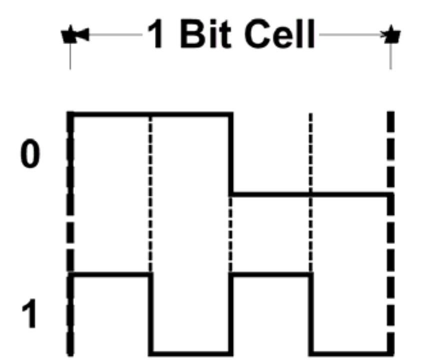


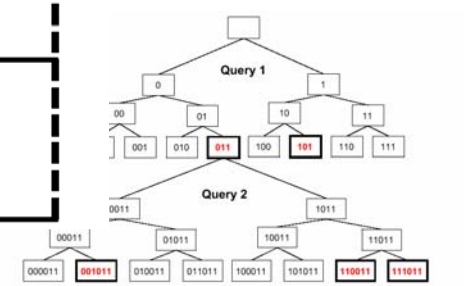


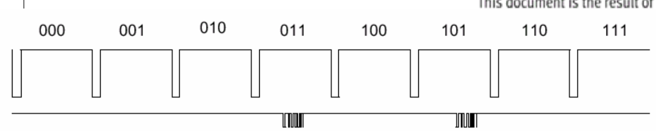




Programming Commands [CMD]	8-Bit Pattern MSB <- LSB	Comment
PROGRAM	0011 0001	
ERASE	0011 0010	After manufacture and Tag has been LOCKed, this bit pattern is used for the WAKE command.
LOCK		
VERIFY		



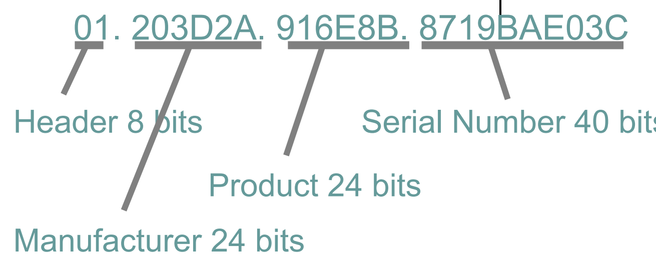




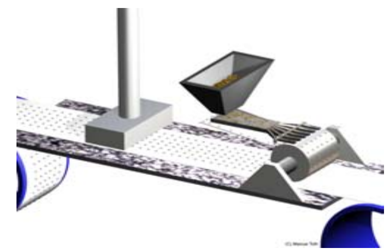
This document is the result of enormous and productive work by the Auto-ID Center's Cheap
esents considerable and ongoing collaboration between Auto-
l Researchers at the Massachusetts Institute of Technology,
Technology, with assistance from Rafsec and Thing Magic, as
delaide. We acknowledge and recognize the generous
emarkable expertise of all concerned.

the hypothesis or bet

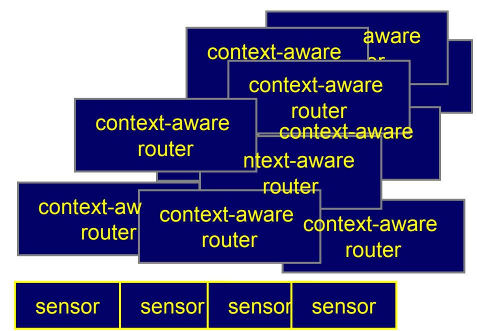
- Place unique number on tag
  - Electronic Product Code, EPC
  - 64 bit, 96 bit, and upwards



- Develop manufacturing technology for small chips and tags



- Move data on the network
  - Network service for resolving EPC
  - Network architecture for gathering and routing data



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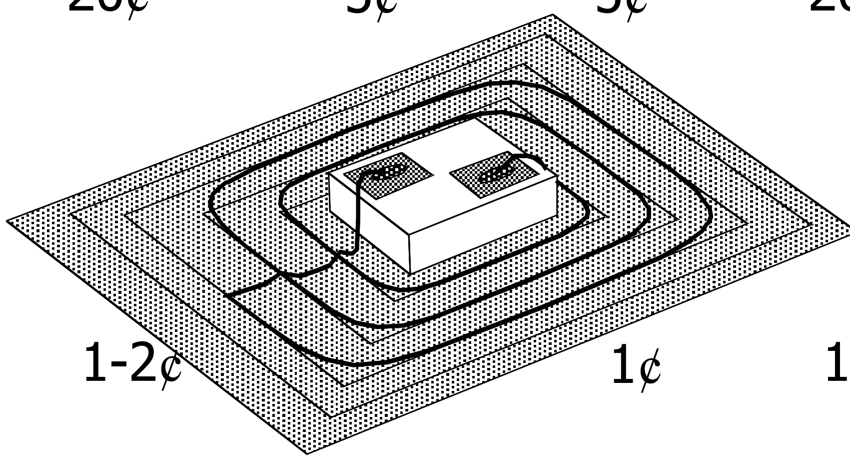
Low cost RFID

IC Design	IC Manufacture	Antenna Manufacture	Antenna/IC Assembly	Conversion to Package	End users
$X Million / Billions Number of tags	20¢	5¢	5¢	20¢	
	1-2¢		1¢	1¢	



Challenges of IC minimalism

- $0.25\ mm^2$: does it make life tougher?
  - ……..
    - Street width will dominate
    - Still have to test the IC's (?)
    - Die handling costs are high
    - Die-attach/wire-bonding techniques do not scale
    - Street width will dominate
    - Still have to test the IC's (?)
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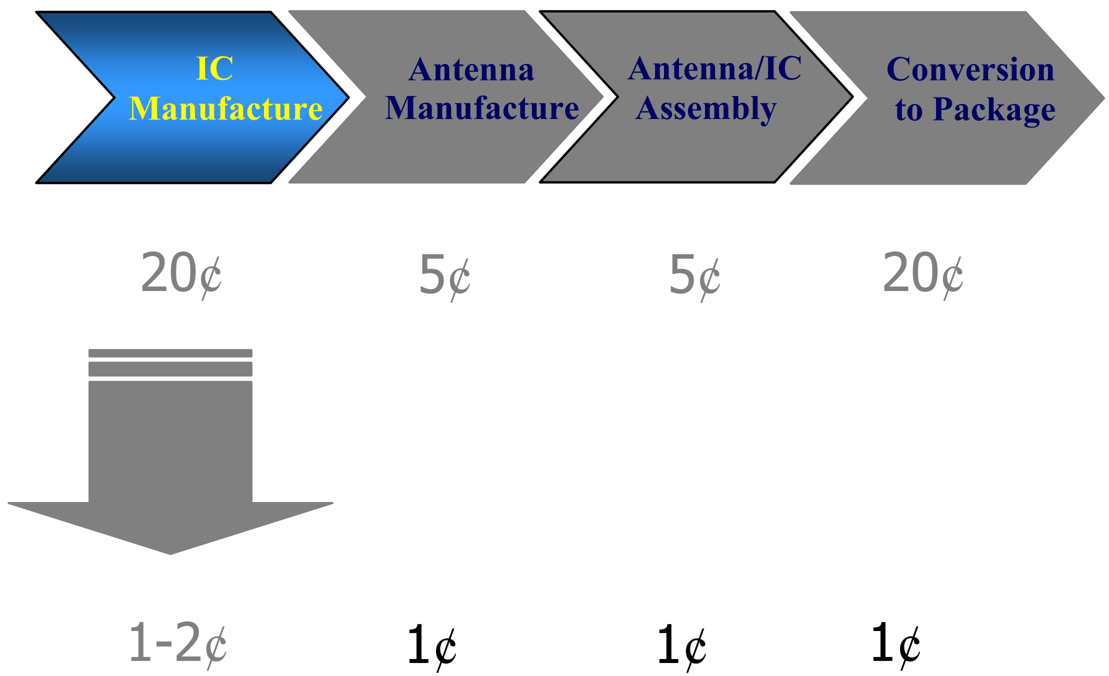
low cost rfid challenges

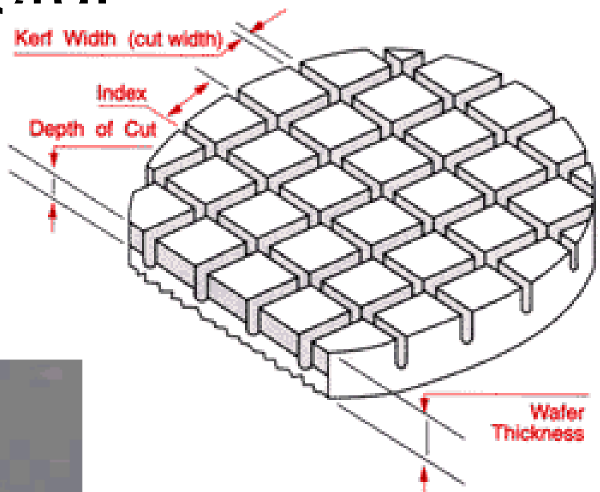


Testing

- Economics today:
  - $500 - $1000 per wafer
- But minimal functionality means
  - High reliability
  - Don't test on wafer
  - Test wirelessly at conversion

Slicing and Dicing

- Standard saw-dicing wasteful
- Instead, use separation by thinning



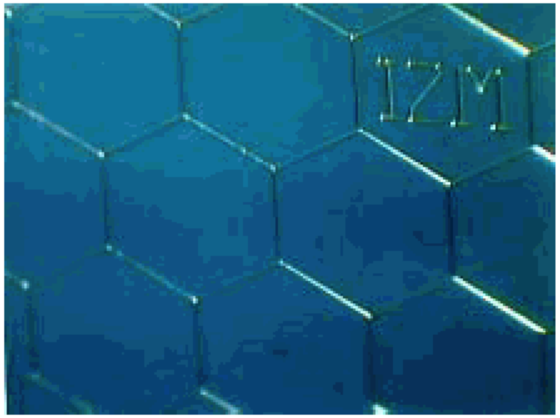


Fig. 6: Handling scheme as proposed by the „Dicing-by-Thinning“ concept; explanations see 5.

C. Landesberger, S. Scherbaum, G. Schwinn, H. Spöhrle: “New Process Scheme for Wafer Thinning and Stress-free Separation of Ultra Thin IC’s,” Proceedings of Microsystems Technologies 2001, Mesago, Stuttgart, pp. 431-436, 2001.

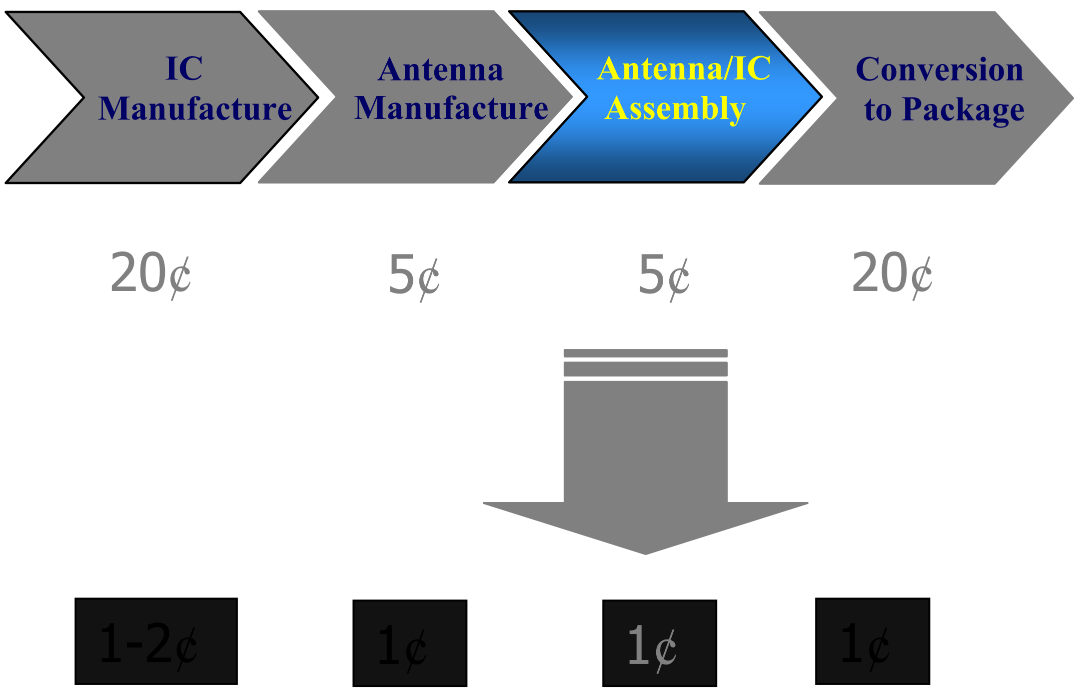
Low cost RFID challenges

IC Manufacture	Antenna Manufacture	Antenna/IC Assembly	Conversion to Package
20¢	5¢	5¢	20¢
1-2¢	1¢	1¢	1¢

Antenna

- Screen printing
- Etching
- Forming

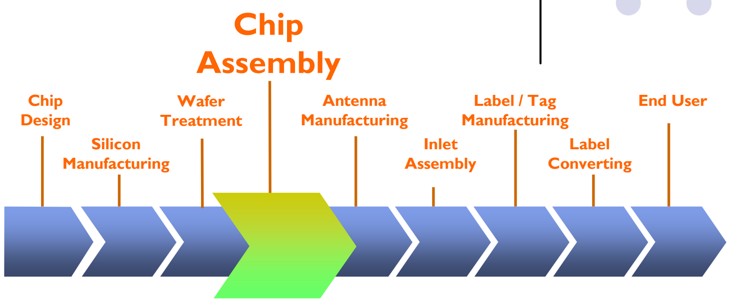
Low cost RFID challenges



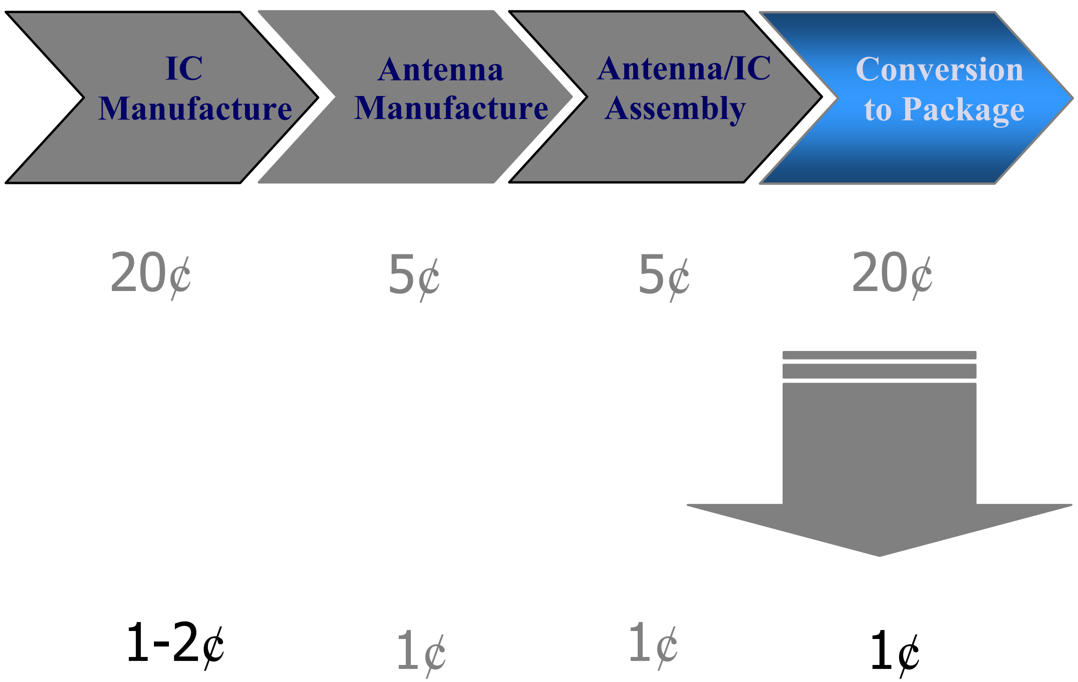
Assembly

- Fluidic Self Assembly
- Vibratory Assembly
- Pick and place

Vibratory Assembly

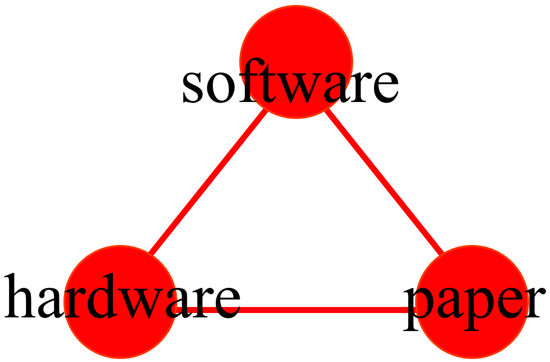


Low cost RFID challenges



Conversion

- Paper/package/label industry expertise
- Scales well with mass production
- Capital equipment expenditure



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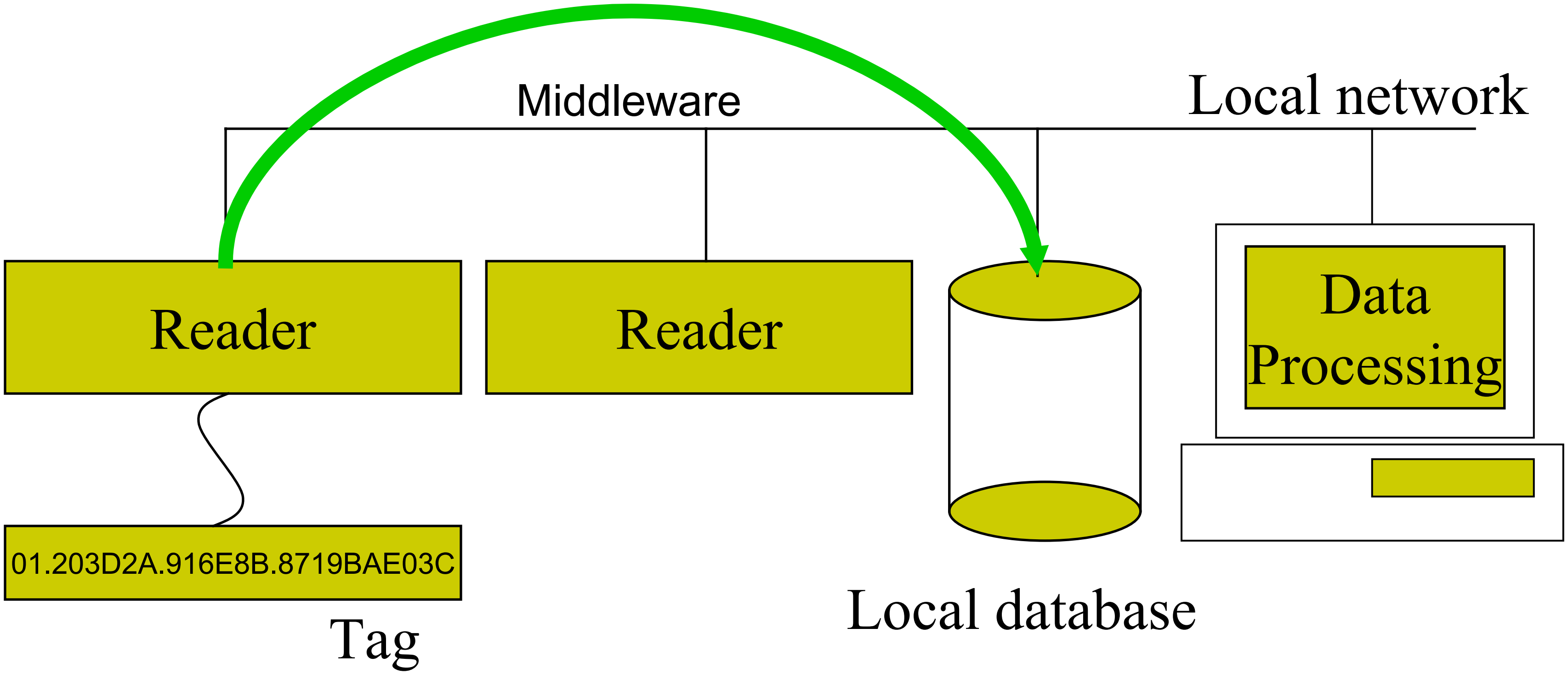
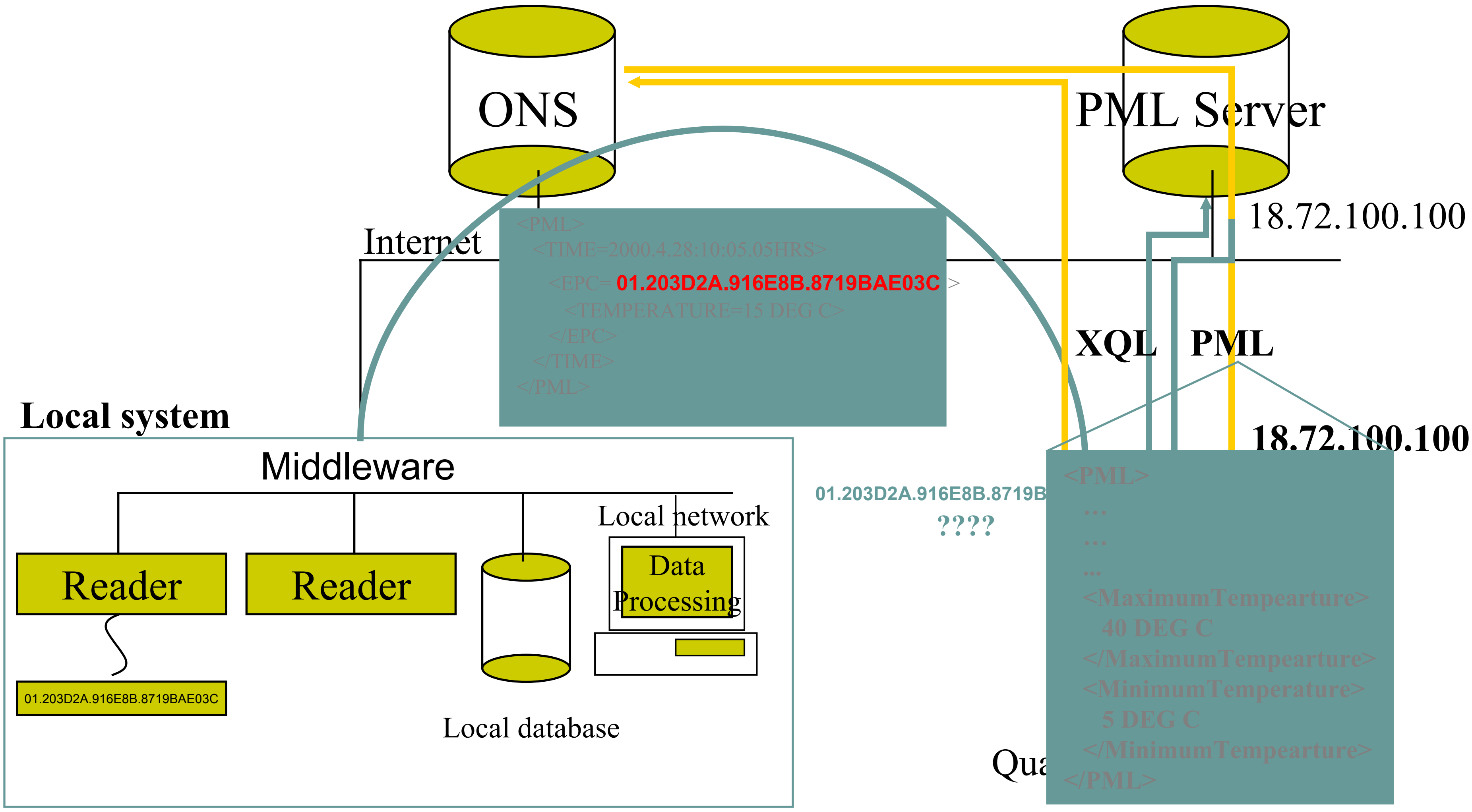
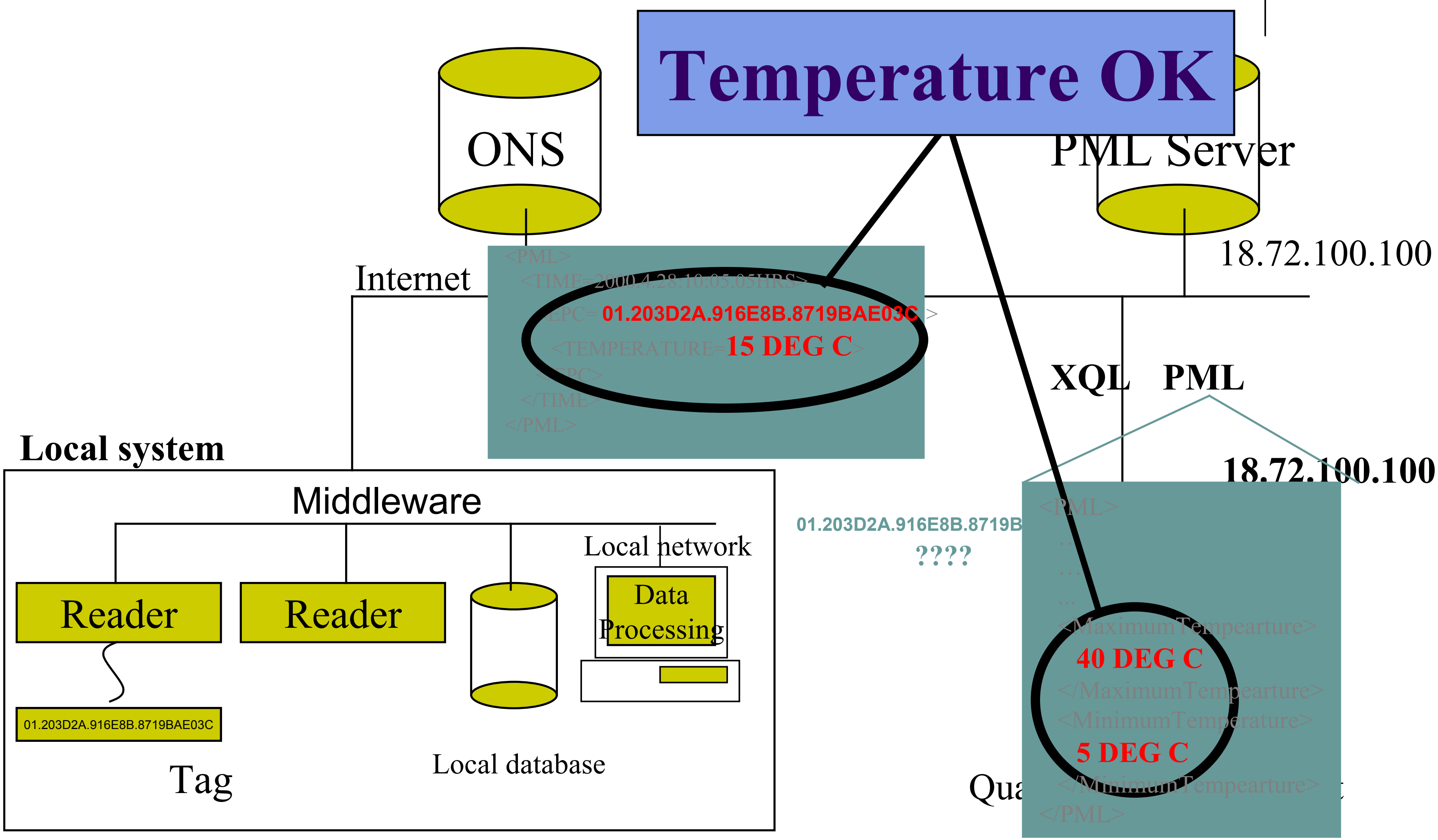
Architecture: Local



Architecture: Global



Inference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ONS
PML Server
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XQL
PML
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Local system
Middleware
Local network
Reader
Reader
Data Processing
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Tag
Local database
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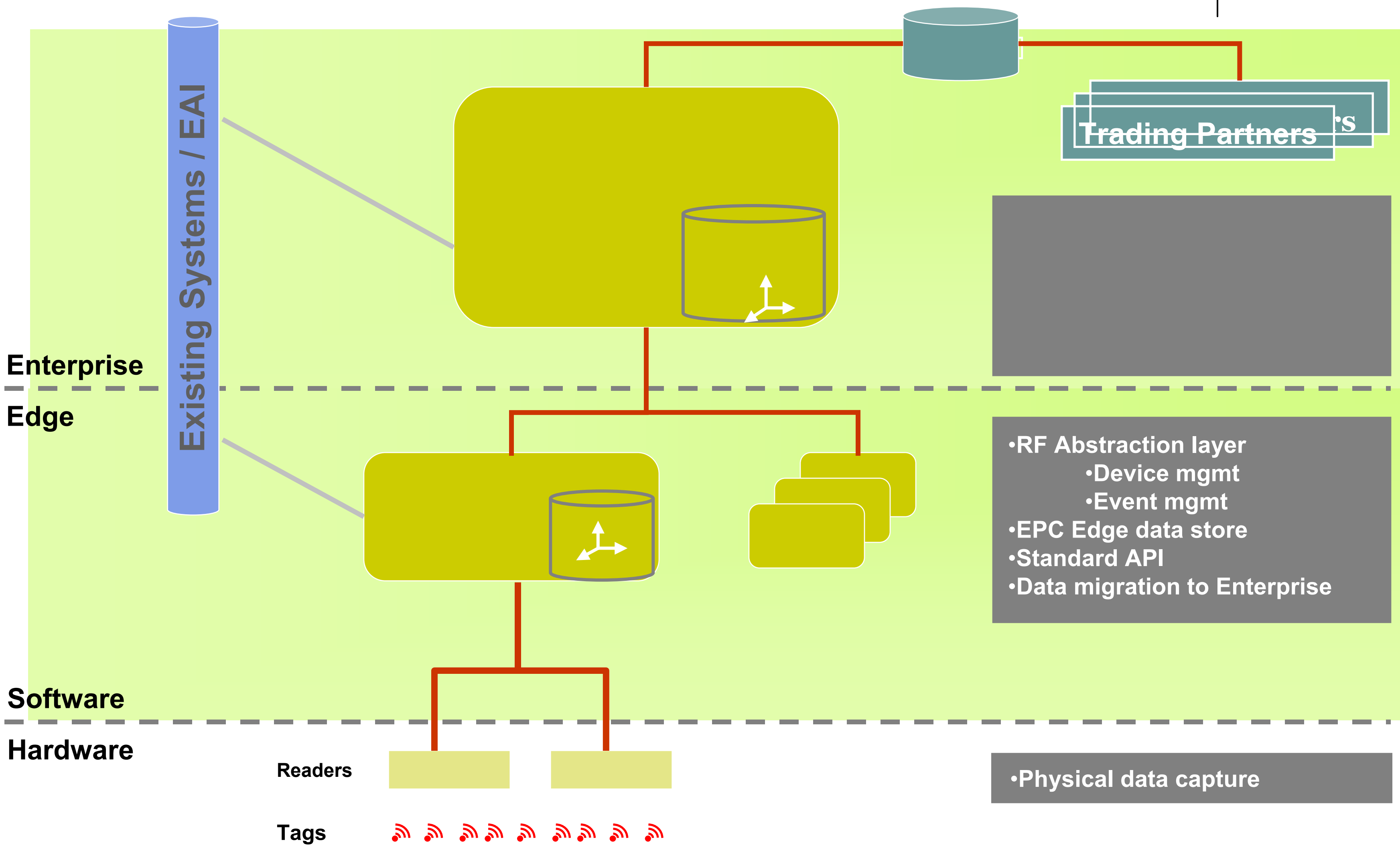
Three Layers of an EPC Architecture



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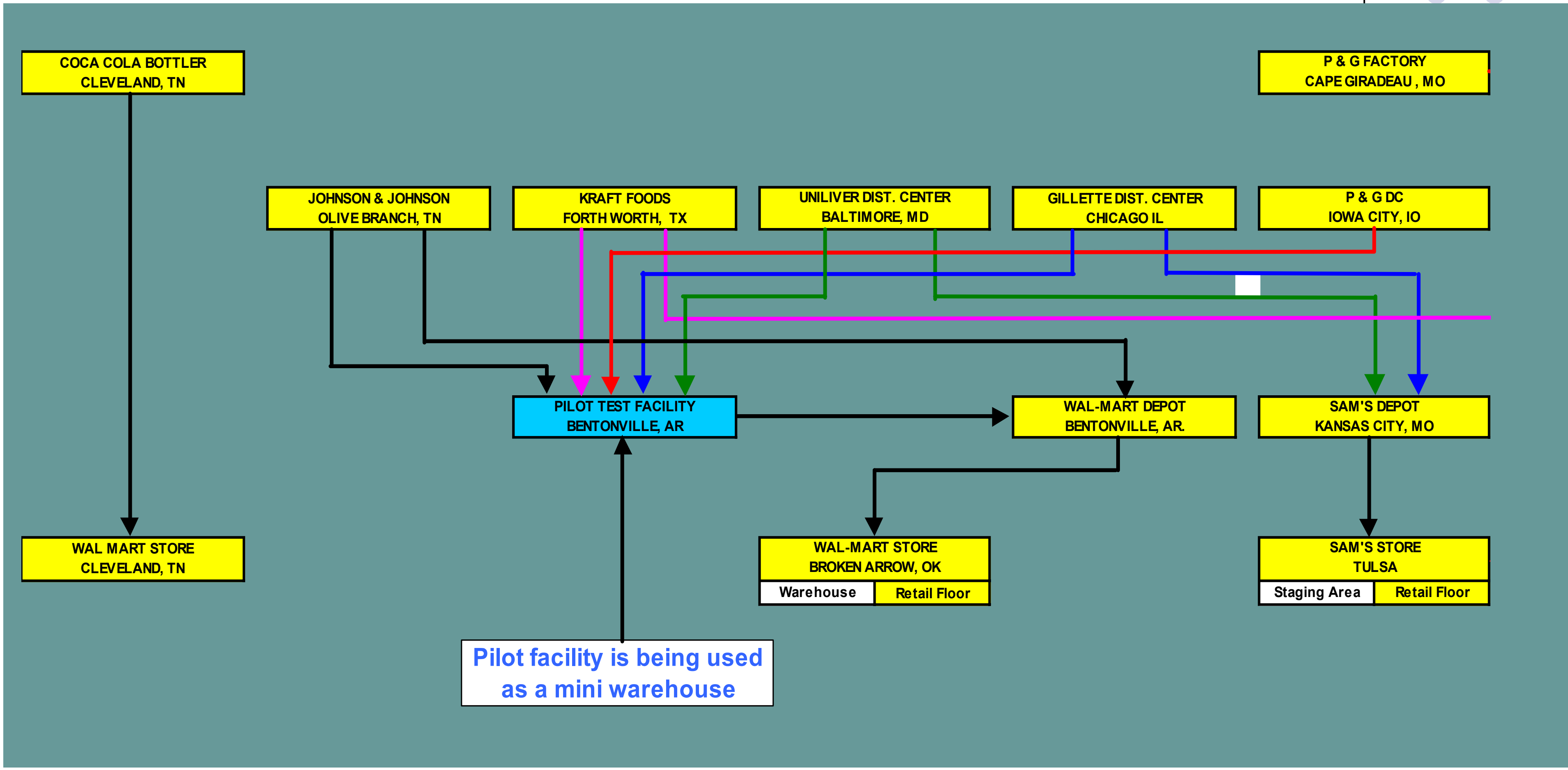
Field Trial


COCA COLA BOTTLER
CLEVELAND, TN
P & G FACTORY
CAPE GIRADEAU , MO
JOHNSON & JOHNSON
OLIVE BRANCH, TN
KRAFT FOODS
FORTH WORTH, TX
UNILIVER DIST. CENTER
BALTIMORE, MD
GILLETTE DIST. CENTER
CHICAGO IL
P & G DC
IOWA CITY, IO
PILOT TEST FACILITY
BENTONVILLE, AR
WAL-MART DEPOT
BENTONVILLE, AR.
SAM'S DEPOT
KANSAS CITY, MO
WAL MART STORE
CLEVELAND, TN
WAL-MART STORE
BROKEN ARROW, OK
Warehouse
Retail Floor
SAM'S STORE
TULSA
Staging Area
Retail Floor
Pilot facility is being used
as a mini warehouse

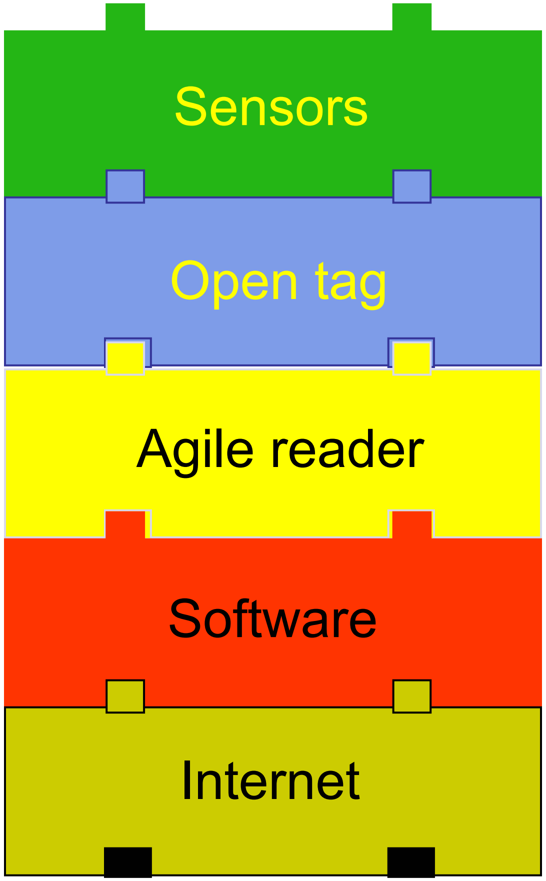
The Commercialization of EPC

- **Landmark Event: EPCglobal is formed**
- Many companies have significant tests and pilots underway
- Mandates:
  - DoD
  - Marks & Spencer
  - Tesco
  - Wal-Mart
  - Metro Group
  - Target
  - Albertsons
  - Best Buy
- Other major retailers are continuing to announce their strategies

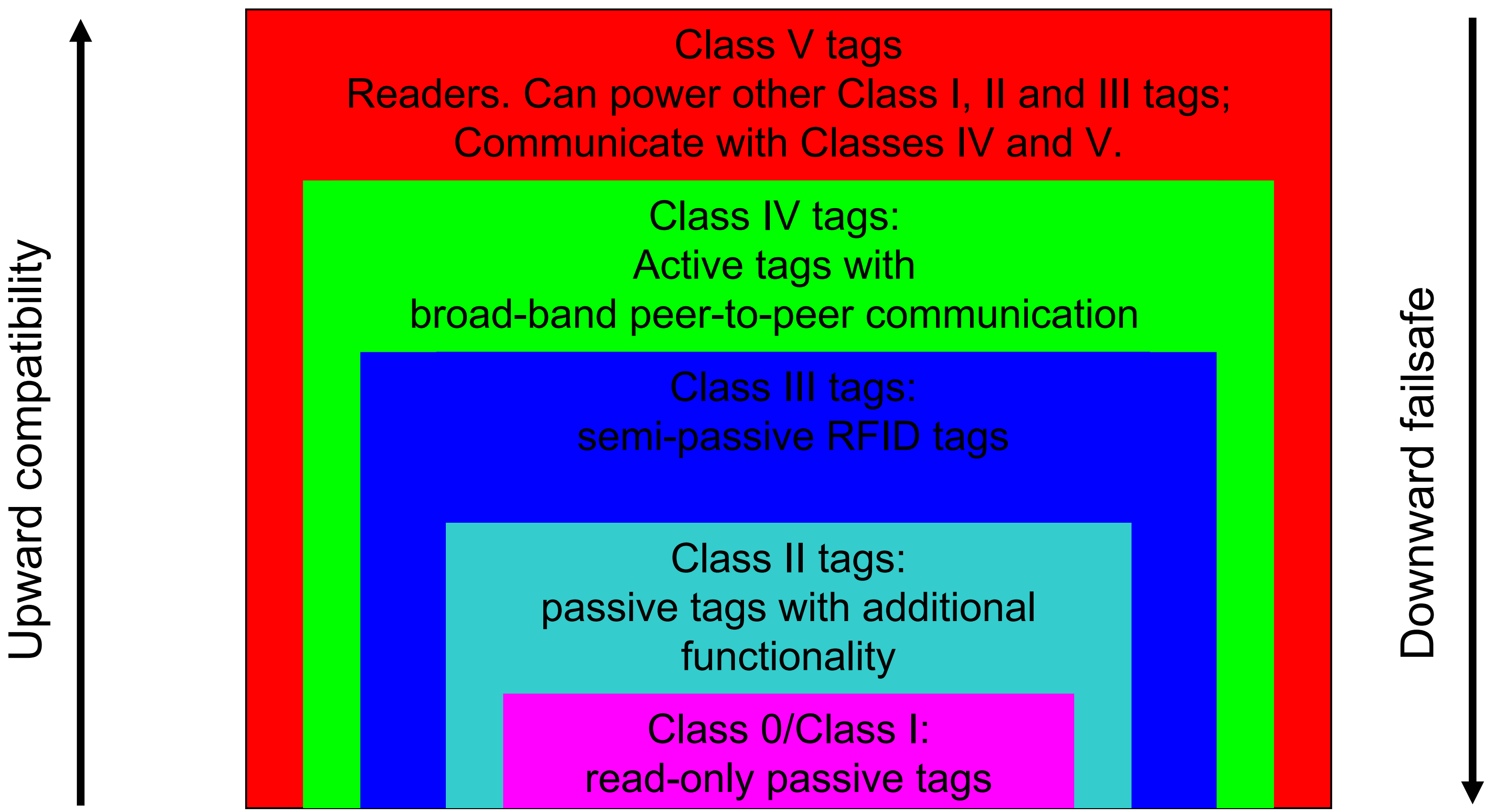
RFID Status

- 3 protocols
  - Class 0 UHF
  - Class I UHF
  - Class I HF
- Tens of manufacturers
  - Tags: Alien, Matrics, Philips, ST Micro, Rafsec, ….
  - Readers: Alien, Matrics, AWID, ThingMagic, Tyco, Symbol, Samsys,…
- New versions being designed
  - Gen 2 taking off
  - Intermec patent still issue

Key philosophy #1: interoperability



Key philosophy #2: Layers



Vendors

- Chips: Alien, Matrics, Philips, ST Micro
- Readers: Alien, Matrics, Philips, Tagsys, Samsys, ThingMagic, Tyco, Symbol, Markem, AWID
- Software: Sun, Oat Systems, Manhattan, Globe Ranger, Conecterra, SAP, Tibco, Verisign, Vizional, ..
- Systems: Accenture, PWC/IBM, GEA, …
- End-Users: Gillette, Wal*Mart, P&G, TESCO, Metro, Target, Wegmans, ….

Research Issues

- Tag anti-collision
- Reader anti-collision
- Security and privacy
- Advanced sensor networks
- Data routing and handling
- IC Design
- IC manufacturing
  - Silicon processing
  - Chip assembly
- Polymers
- Controls/automation

- Manufacturing systems
- System Synthesis
- Supply chain issues

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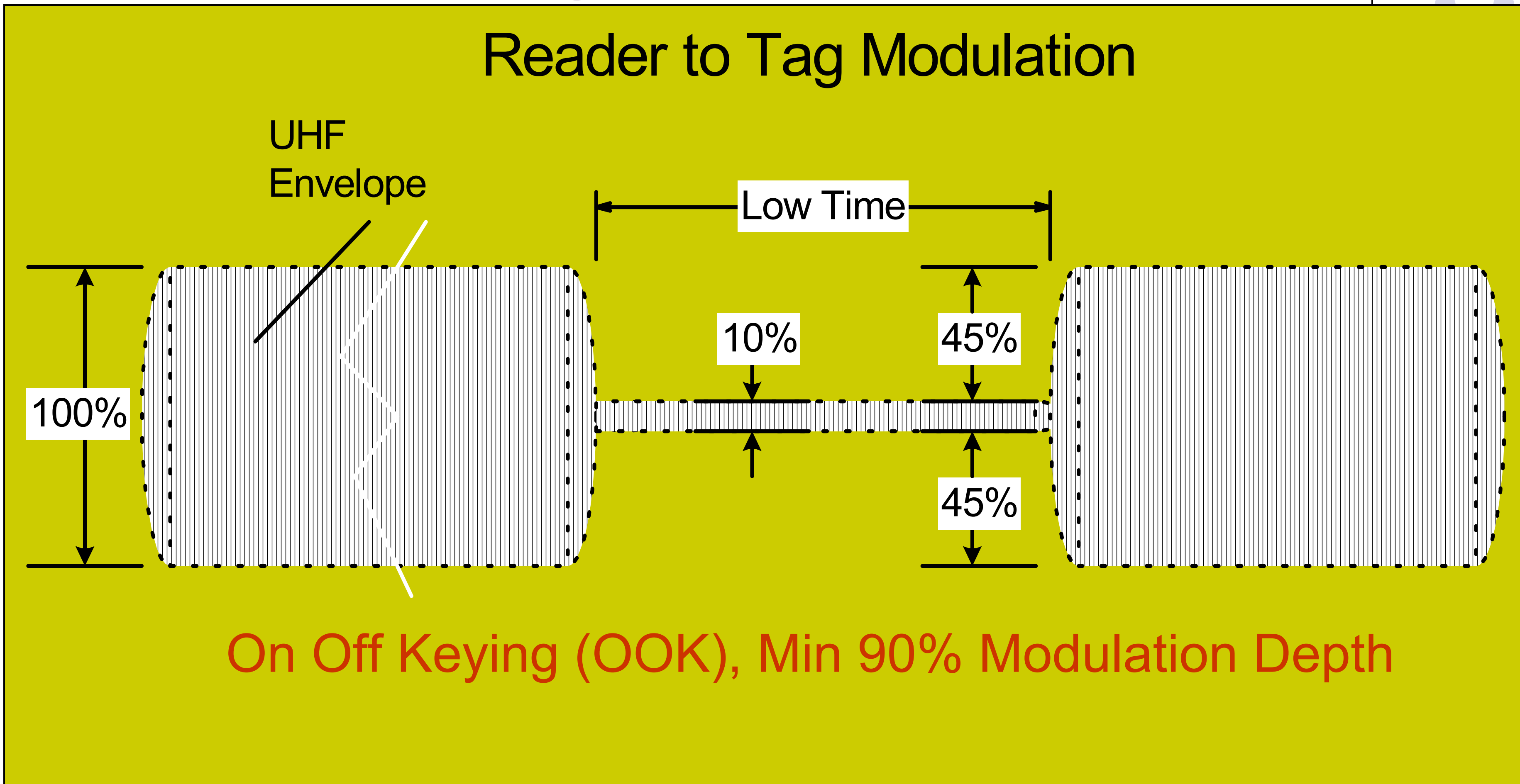
  - Security and Privacy Issues
  - Software
  - Vibration analysis
  - Silicon manufacturing

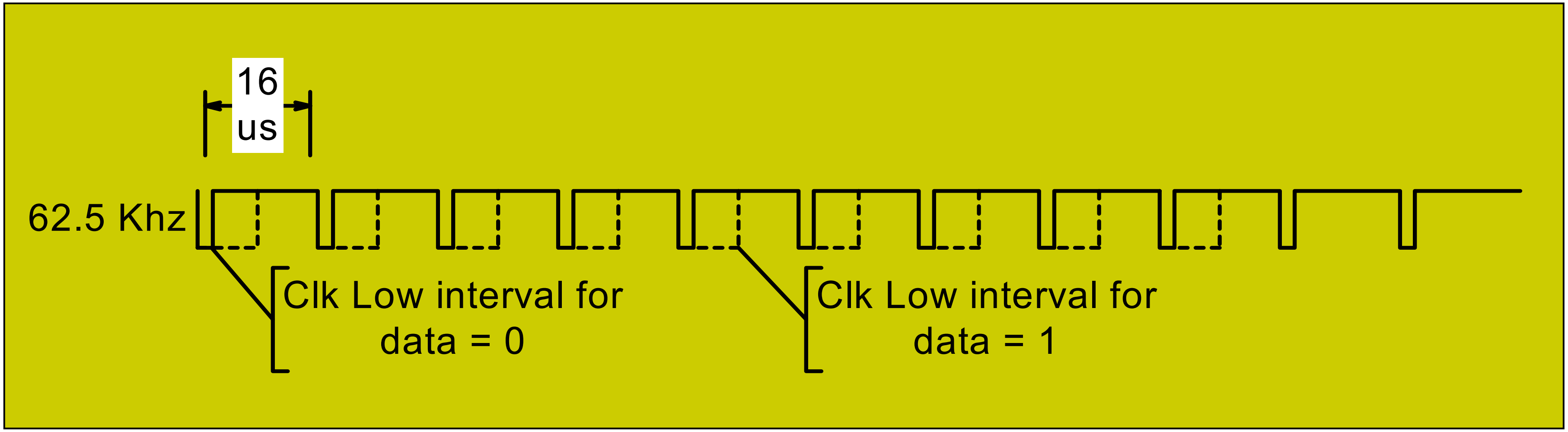
Components

- Signaling
- Anti-collision
- Functions

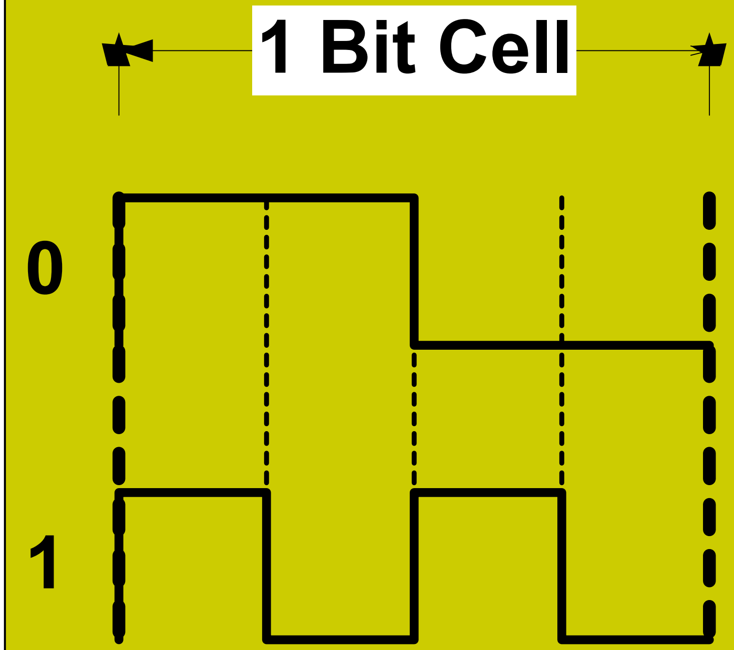
reader to tag: modulation



Modulation: reader to tag



tag to reader



- Bit Cell Time: ~8 μs Tag to Reader (128 kbs)
- 2 Transitions = 0
- 4 Transitions = 1
- Always Transitions Within a Bit

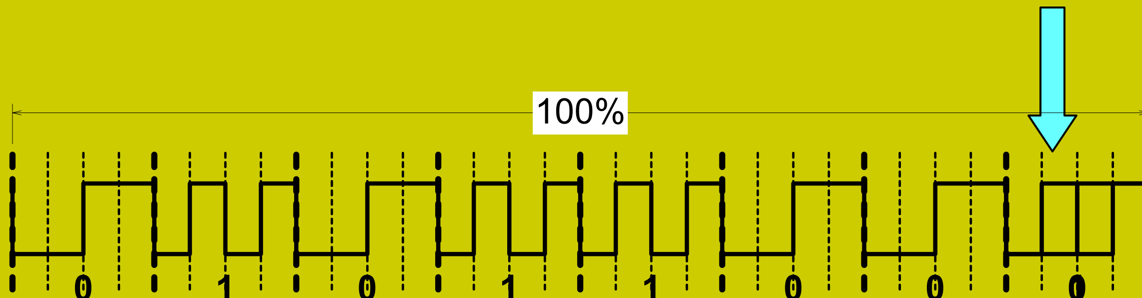
Anti-collision

- A Reader Talks First (RTF) System
- Commands Issued from Reader
- Tags Reply at a Later Time While Reader Listens
- Transactions are Self-Contained Operations (Minimal Persistent State Information Required)

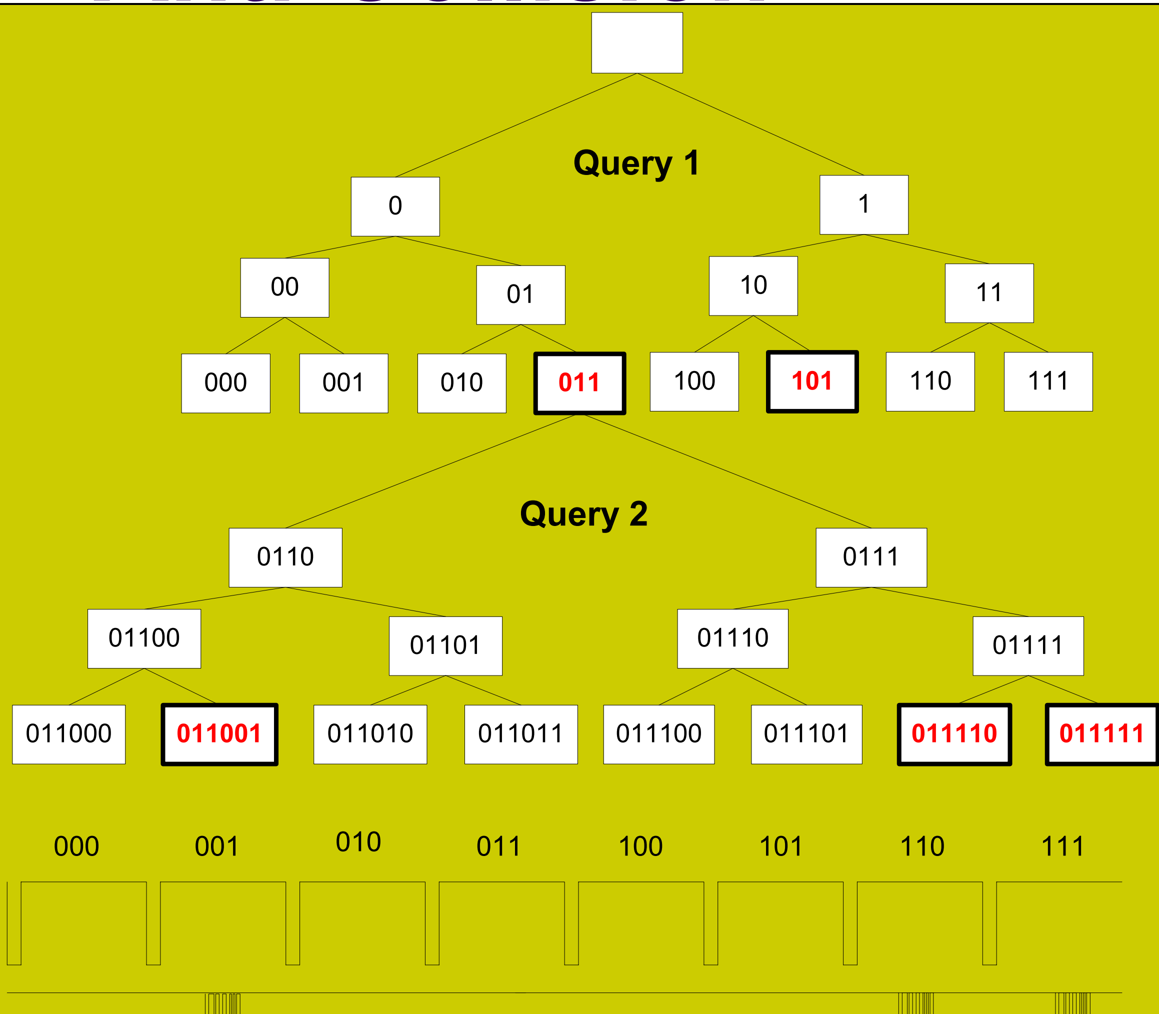
Contention Detection

Anti-Collision Algorithm Relies on Detecting Contention (When More than One Tag is Responding to a Reader Command).

Contention- Two Tags, Same Clock Rate, 1-Bit Difference



Anti-Collision



[CMD] = 00001000 (Ping)
[PTR] = 00000000
[LEN] = 00000000 (0)
[VALUE] = 0

[CMD] = 00001000 (Ping)
[PTR] = 00000000
[LEN] = 00000011 (3)
[VALUE] = 011

Functions

- Write address
- Lock address
- Preload address mask
- Read ID (anti-collision)
- Read payload
- Write payload
- Sleep
- Wake
- Destroy

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  - A peek at the protocol
  - Security and Privacy Issues
  - Software
  - Vibration analysis
  - Silicon manufacturing

Does protocol compromise privacy?

Not necessarily. Your choice.

- You can destroy the tag and opt out
- or
- You can keep tag for later use
- (physics is your friend)

Mass hijack of tags

- Could happen in <u>destroy</u> or <u>re-programming</u>

- Physics our friend
  - Bandwidth limited: 100's of tags a second anti-collision
  - <u>Destroy</u> must be individually addressed
  - So it takes time to kill
  - Surveillance

Issues

- <u>Tags are light-weight</u>

- Anyone can read the tags (promiscuity)
- The same number shows up all the time
- Channel is open and shared

01. 203D2A. 916E8B. 8719BAE03C

Header 8 bits

Manufacturer 24 bits

Product 24 bits

Serial Number 40 bits

Problem: unique and promiscuous

Kill Serial number?

- Product still readable
- Person can be tracked by constellation

Personalize the number?

- Repeated reads yield same number
- You could still be tracked by constellation

Check out EPCglobal

Public policy

www.**epcglobal**inc.org/**public_policy**/**public_policy**_guidelines.html

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Outline

- Introduction
- Kinematics
  - In-plane surface motion
  - Out-of-plane motion
- Adhesion and fluid effects
- Experiments
- Conclusions

Introduction

Motivation

- Need methods for handling of small microscopic parts in tag production processes
- A traditional technique to solve scaling problems is parallelization

Topics

Basic kinematics of vibratory part transport

Effects of fluid, and surface/adhesion forces

Outline

- Introduction
- Kinematics
  - In-plane surface motion
  - Out-of-plane motion
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- Conclusions

Vibration Kinematics

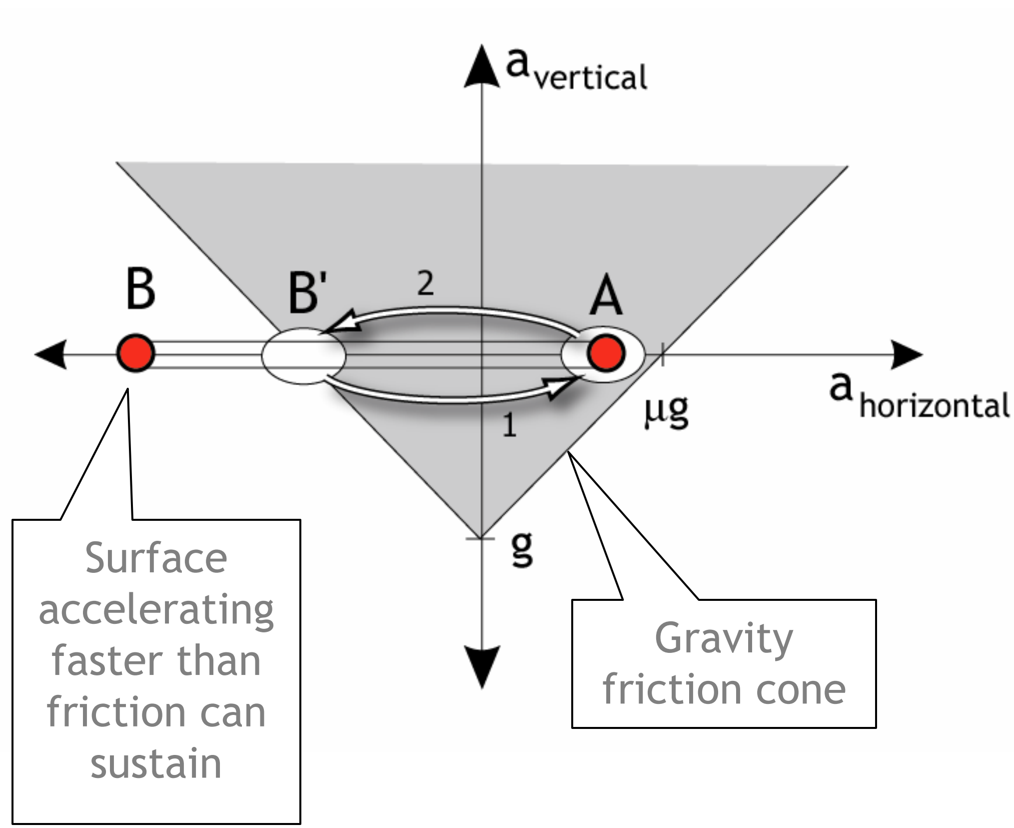
- Want relative motion
- Approaches:
  - Surface micro-features
    - MEMS cilia, rollers, etc.
    - Gas flow nozzle arrays
  - Electrical/magnetic fields
  - Moving Fluid medium flowing over surface
    - Fluidic Self Assembly (FSA Alien Tech’s)
  - Vibrating surfaces
    - Time asymmetric in-plane vibrations
    - Out-of-plane vibrations (such as in Bowl Feeders)

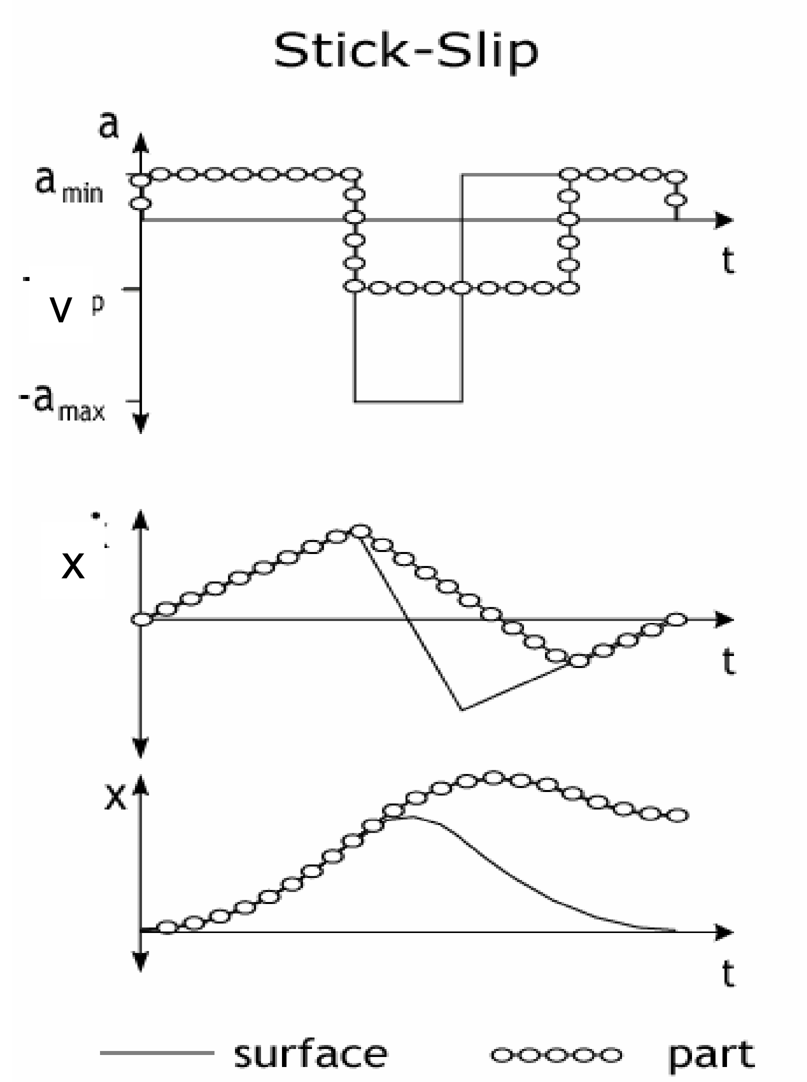
Vibrating Surfaces

In-plane vibrations of a surface if time-asymmetric

- Part moves if surface acceleration is more than friction
- Forward-backward motion?
- Much literature

Example: Stick Slip

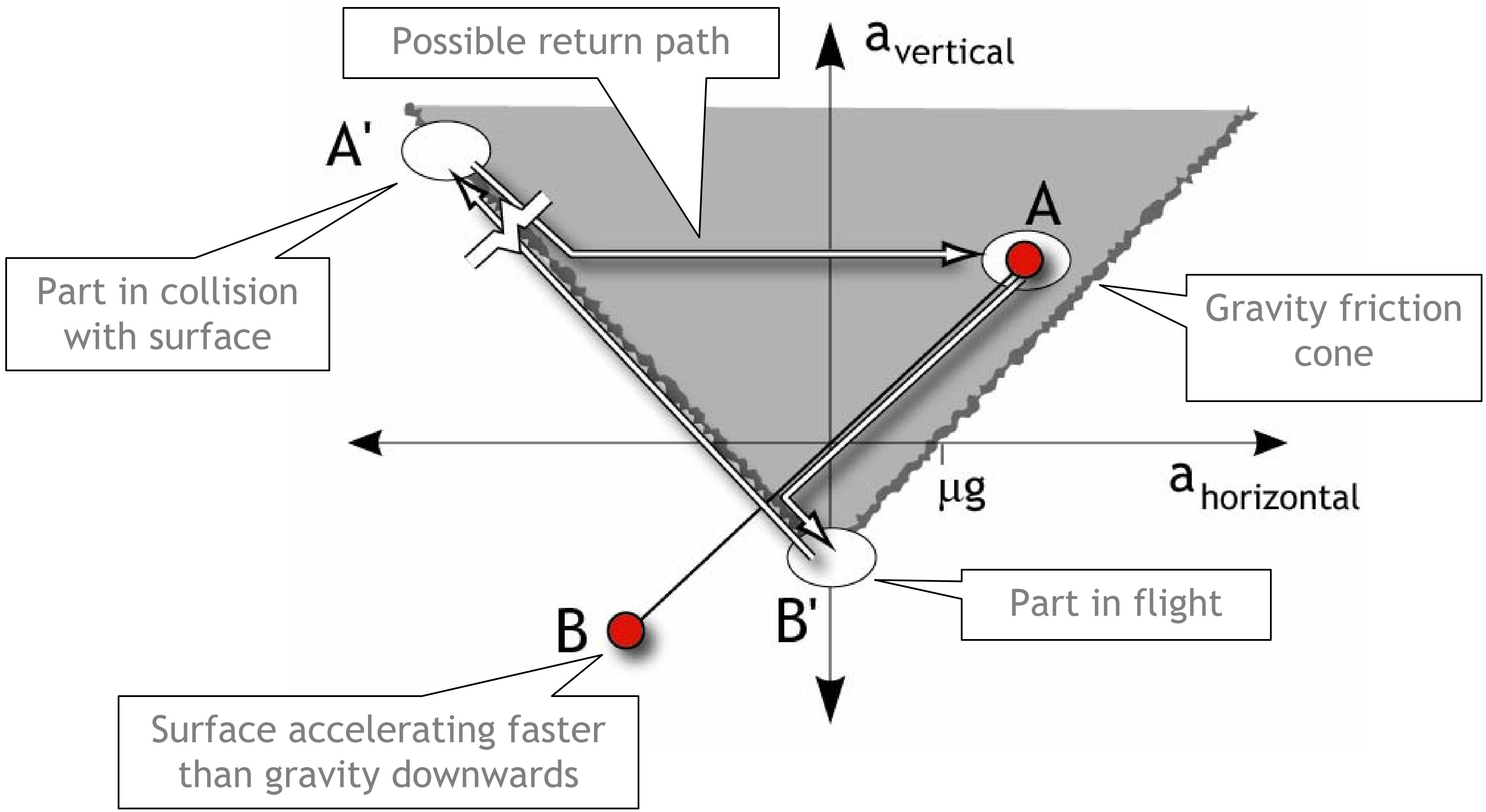




Out-of-plane vibrations

- Vertical vibration: extra degree of freedom
- Create hop, move platen back
- Small-scale forces
- Increased accelerations may be needed to compensate

Hopping example



Outline

- Introduction
- Kinematics
  - In-plane surface motion
  - Out-of-plane motion
- Adhesion and fluid effects
- Conclusions

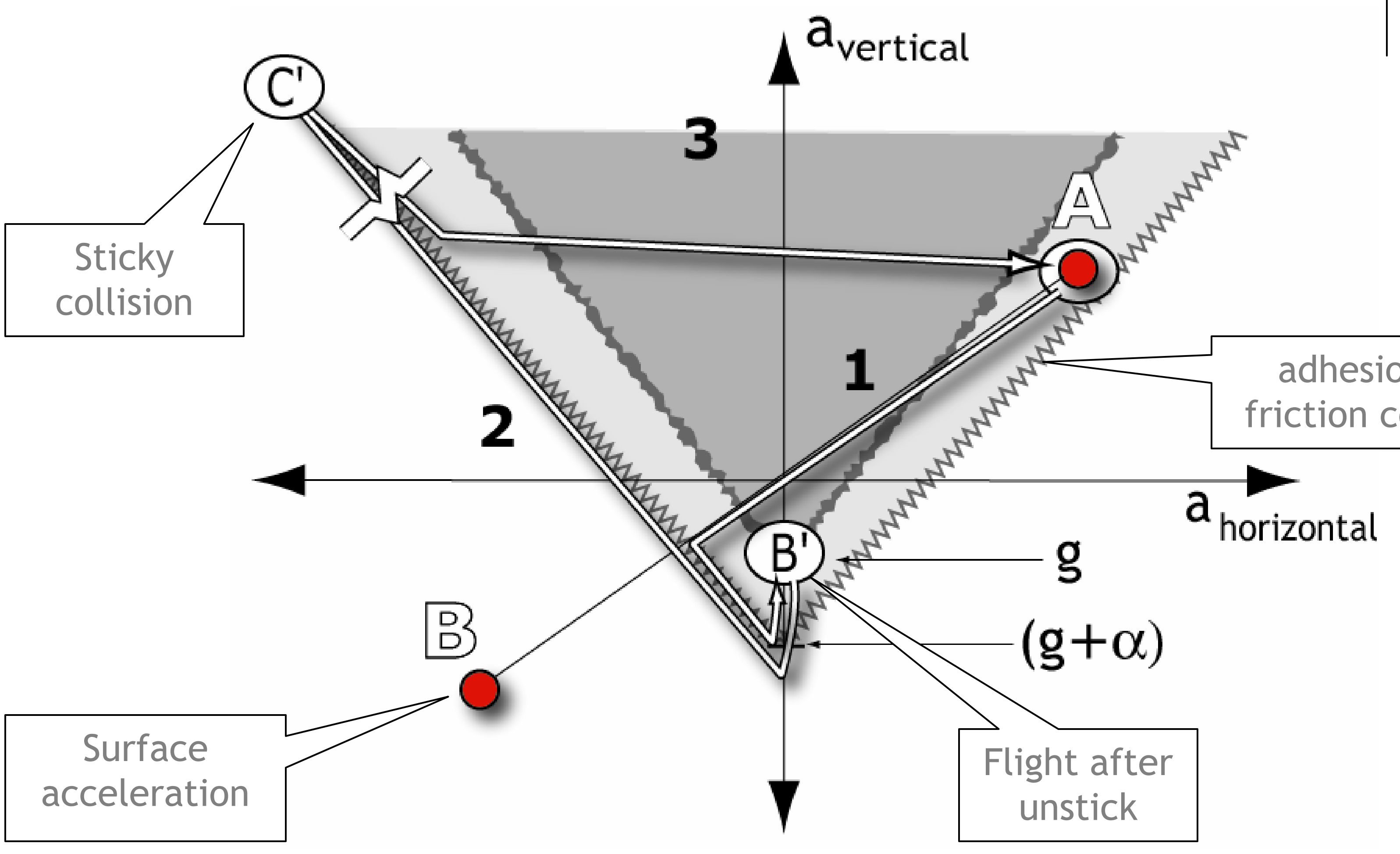
Adhesion

- Adhesion effects become important at small scales
- Van der Waals forces
  - Due to static and quantum mechanically induced dipoles
  - Strong role in inter-molecular and surface phenomena
  - Become important at < 100nm surface separation
  - Adhesion surface energies of ~100mJ/m^2
  - Clean atomically smooth surfaces in contact may have adhesion pressures of the order of thousands of atmospheres

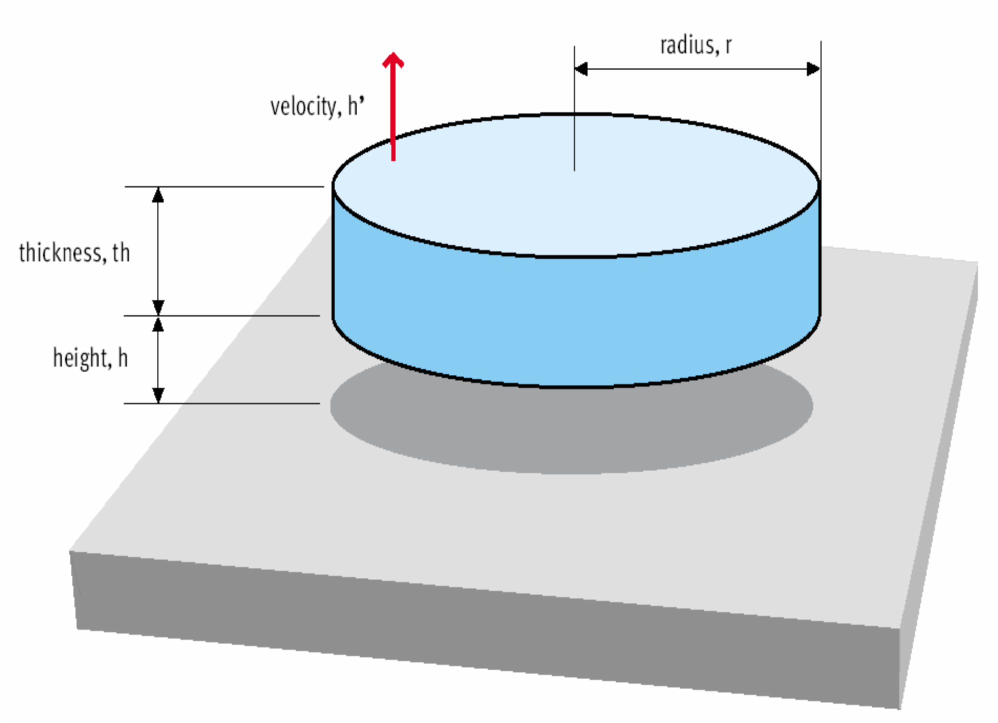
Adhesion effect on vibratory transport

- Larger accelerations are needed
- Too contaminated or too clean are bad
- Can be alleviated by: Roughening or Surfactants
- Strong secondary excitation can “levitate” the parts
    - If done for fractions of the cycle, “creeping” transport can be achieved, where the part moves when vibrations are on and sticks when they are off

Example: hopping with adhesion



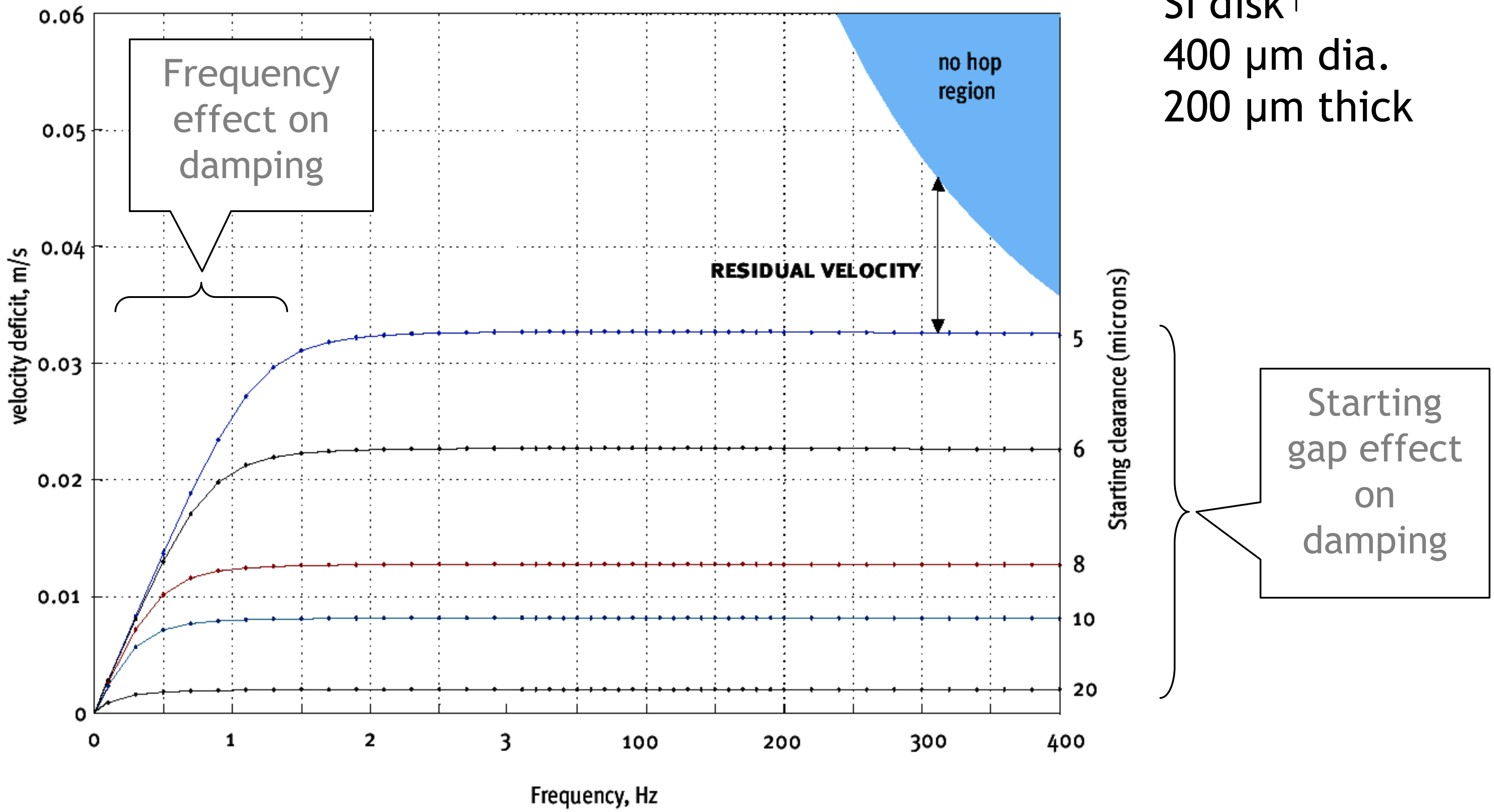
Fluid dynamic scaling



- Sticking due to fluids
- Alleviation
  - use surfaces that are “leaky”
  - Make chip surface bumpy
  - Run in vacuum

velocity loss due to film damping

Si disk
400 μm dia.
200 μm thick



Outline

- Introduction
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- Conclusions

Conclusions

- Basic physics
- Ongoing work:
  - Measurements
  - Effects of geometries
  - Test methods
- Design:
  - Chip delivery methods and roll to roll packaging

Outline, Part II

- RFID and the Auto-ID Center
- An in-depth look at some issues
  - A peek at the protocol
  - Security and Privacy Issues
  - Software
  - Vibration analysis
  - Silicon manufacturing

RFID manufacturing simulation

Gita Swamy
Sanjay Sarma

Outline

- Components of an RFID tag
- Understanding the Experiment
- Manufacture
  - Semiconductor
  - Tag
- Results
- Worldwide Fab Capacity

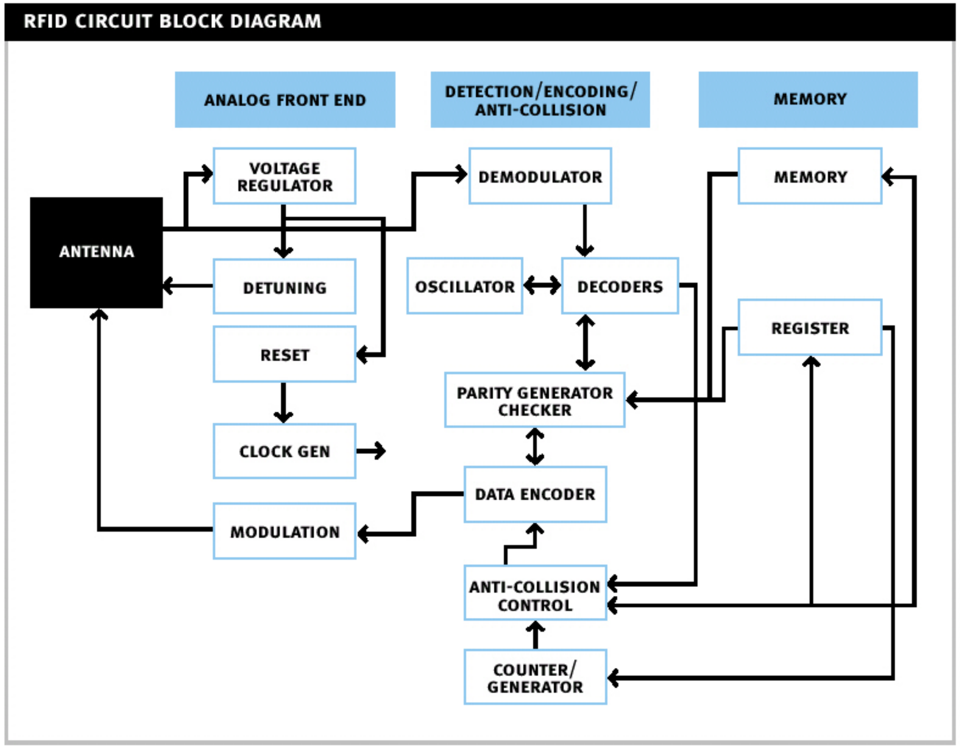
Results

- Total RFID Cost
  - IC + Traditional Assembly: 4.351¢
  - IC + Flip Chip Assembly: 3.311¢
- IC Cost: 1.151¢
- Antenna Cost: 11¢
- Assembly: 2.25c ~ 1.15 1¢

- At 10's of billion tags a year

RFID Tag Components

- Antenna
- Mixed-Mode IC
- Packaging



Inputs to model

Process Steps

Equipment Benchmark

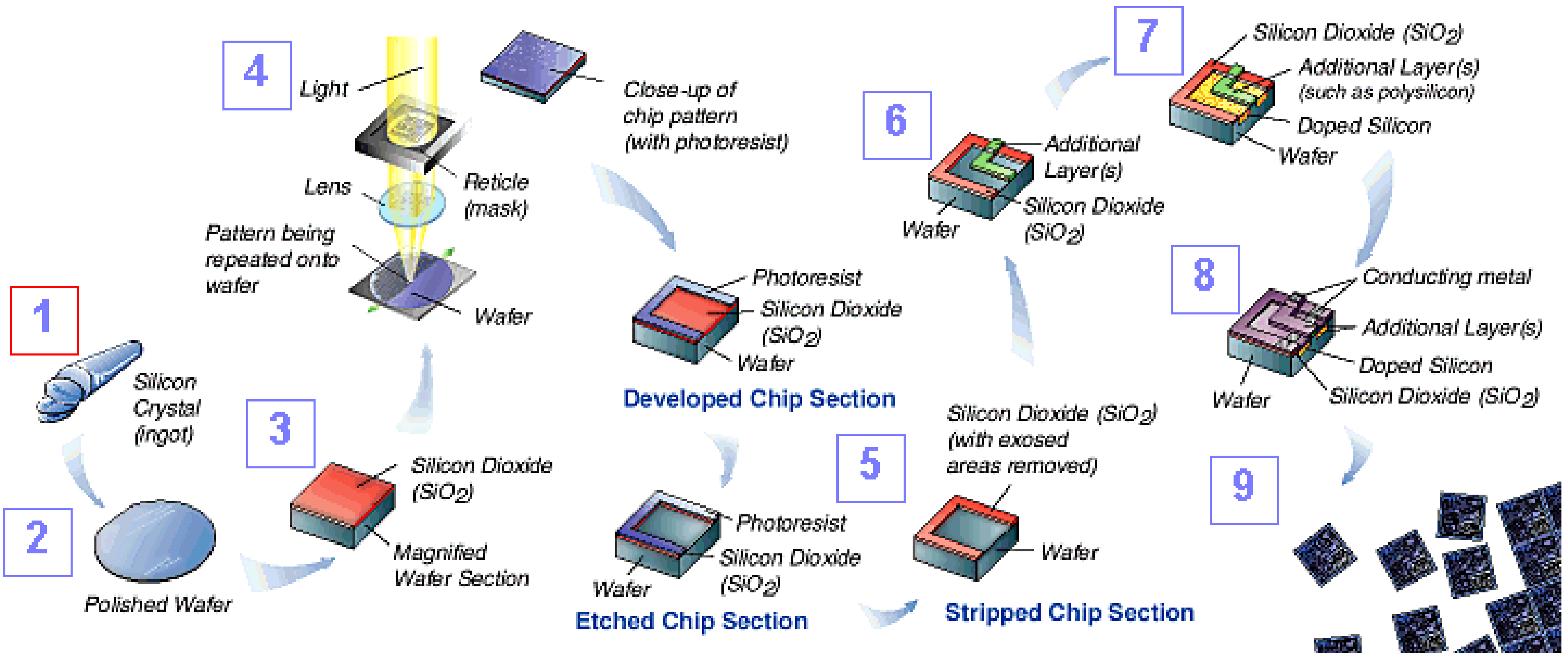
- Throughput
- Raw material & Utilities
- Labor
- Yield

Overhead

Maintenance

Depreciation

Semiconductor Processing



Process modeling

- **R. Leachman, J. Plummer & N. Sato-Misawa, "Understanding fab economics"** Competitive Semiconductor Manufacturing, University of California, Berkeley, 1999.
- **Leachman & Hodges, "Berkeley Semiconductor Manufacturing"** IEEE Transactions on Semiconductor Manufacturing, May 1996.
- **J. Bloomsburg, "RFID Tag Manufacturing"** MIT UROP, 2002.
- **R. Wright, "Cost Resource Model Detail"** Economic Model Workshop, International Sematech, 2001.

semiconductor process modeling

- Sematech developed benchmark
- 250_A1_82 Process Benchmark
  - 0.25 micron
  - 282 Step
  - 19 Mask
  - 3 Metal
  - 2 Poly

PROCESS DESCRIPTION	TOOL_TYPE
Expose_Implant	Litho_lw
Meas_Overlay	Meas_Overlay
Inspect_PLY	Insp_PLY
Meas_CD	Meas_CD
Implant	Implant_HiE
Implant	Implant_HiE
Implant	Implant_LoE
Plasma_Strip	Dry_Strip(I)
Clean_Post_Strip	Wet_Bench(I)

Driving Variables

- Mask, Metal and Poly Layers
- Wafer starts: 300,000 per year
- 100,000 dies/wafer
- Wafer size: 200mm

Input	Comment	Value
Mask Layers		25
Metal Layers		3
Poly Layers		2
Base calculation number dies		50000
Number of dies per wafer		114,182
Feature Size in mm		1
Total cost per wafer		1321.61
Total cost per die		0.01157462
Worldwide fab capacity		66,560,000
Wafer starts		300,000
Utilization		0.45%

Create New Process

Clear

Sensitivity

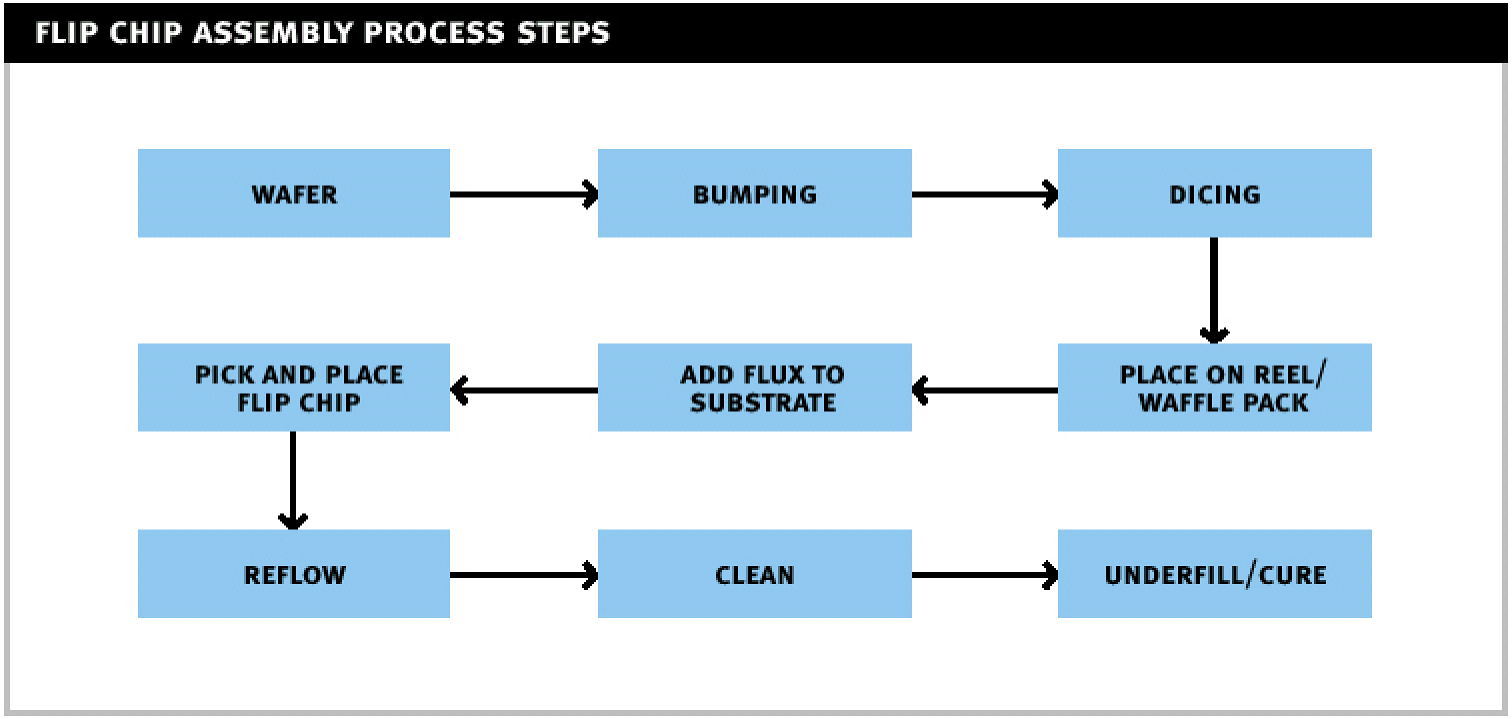
Poly 1

		Metal					
	$0.01157462	**1**	**2**	**3**	**4**	**5**	**6**
Mask	**7**	0.007118275					
	8	0.007235116					
	10	0.00746513	0.008581733				
	15	0.008039686	0.009164546	0.010289017	0.011411	0.012532	
	20	0.008629255	0.009748212	0.010873598	0.011991	0.013123	0.014244
	25	0.009209519	0.010328784	0.011453179	0.012579	0.013702	0.01482

Assembly Process

- Assembly Process Steps
  - Thinning
  - Dicing
  - Assembly
    - Traditional
    - Flip Chip
    - Fluidic Self Assembly
    - Vibratory Assembly
  - Tag Test

Flip chip


FLIP CHIP ASSEMBLY PROCESS STEPS
WAFER
BUMPING
DICING
PLACE ON REEL/ WAFFLE PACK
ADD FLUX TO SUBSTRATE
PICK AND PLACE FLIP CHIP
REFLOW
CLEAN
UNDERFILL/CURE

Assembly Process

- Types of Runs
  - Unit Machine
  - Line Maximized

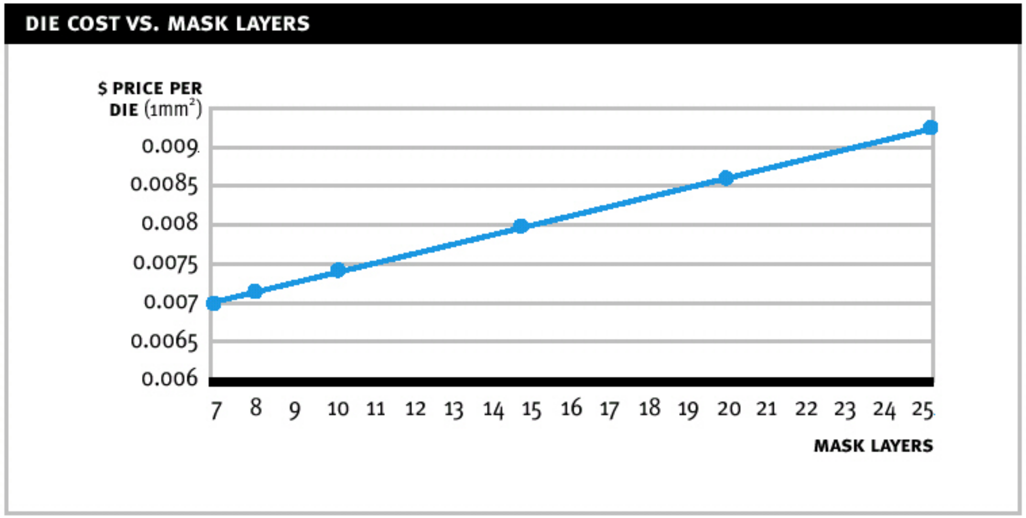
Process	Throughtpu Unit/Hr	Pipeline Tput Die/Hr	Used Tput Die/Hr	Utilizatic Hr/Day	Active Life Yr	Yield %	Wattage KW	Floor space Sq Ft	Machine Cost $	Maintainence cost $/Yr	Total Cost $/Yr
Thinning	10	1130400	1130400	16	5	97%	20	100	$425,000	$5,000	**$101,923.4**
Dicing	6	678240	678240	16	5	97%	20	21	$300,000	$5,000	**$72,164.0**
Traditional Assembly	3750	3750	NA	16	5	97%	20	200	$935,000	$5,000	**$216,983.4**
Flip Chip Assembly	10000	10000	10000	16	5	98%	20	150	$1,200,000	$5,000	**$273,853.4**
Tag Test	7200	7200	7200	16	5	97%	20	55	$140,000	$5,000	**$37,936.4**

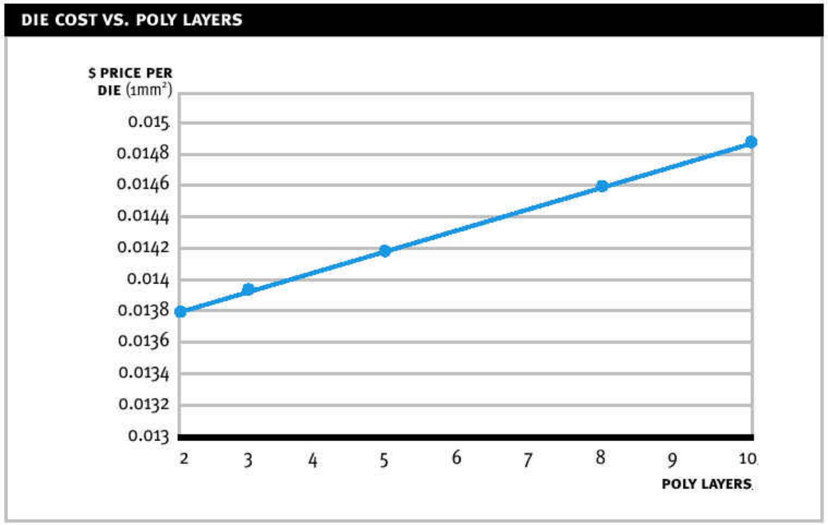
Results

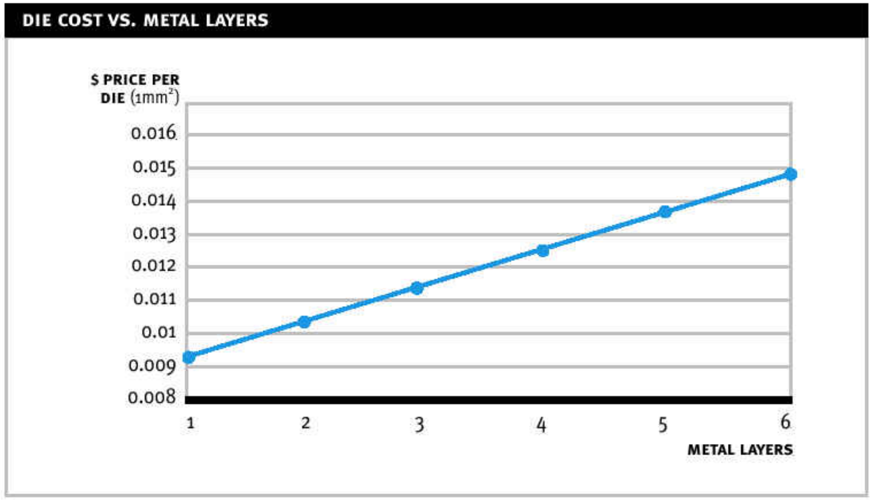
- Total RFID Cost
  - IC + Traditional Assembly: 4.351¢
  - IC + Flip Chip Assembly: 3.311¢
- IC Cost: 1.151¢
- Antenna Cost: 11¢
- Assembly: 2.25c ~ 1.15 1¢

- At 10's of billion tags a year

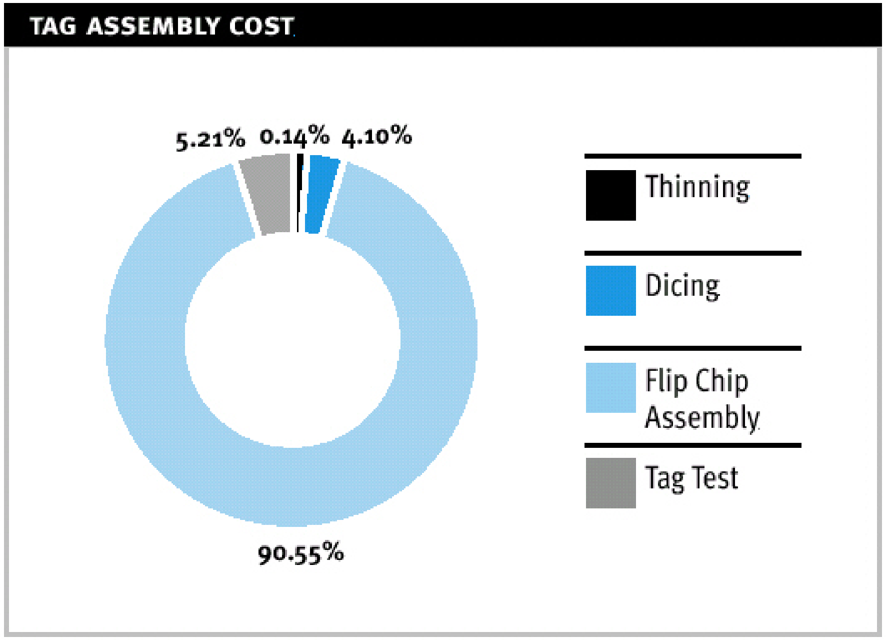
Results: Die Cost



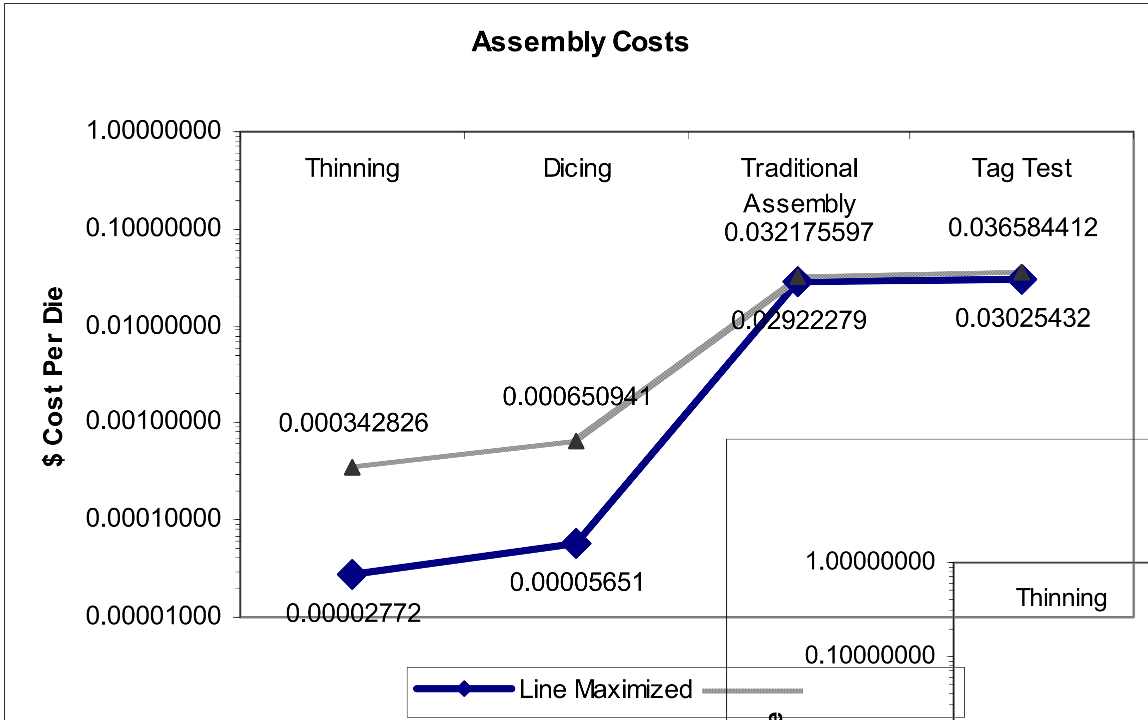


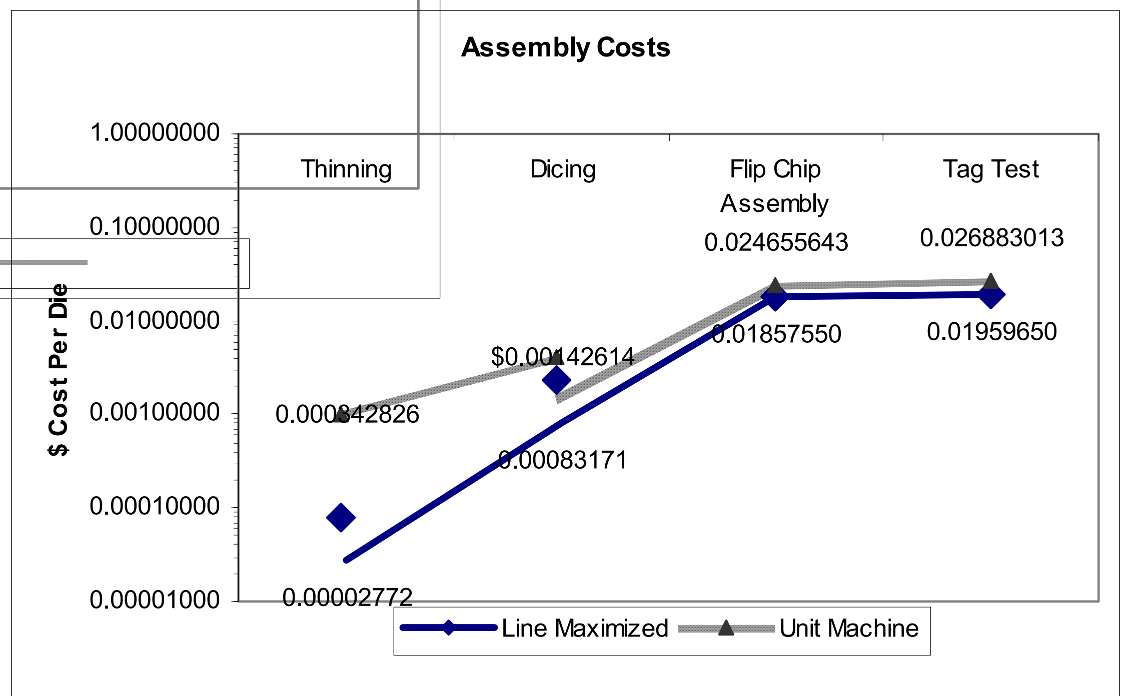


Results: Assembly Cost Breakdown

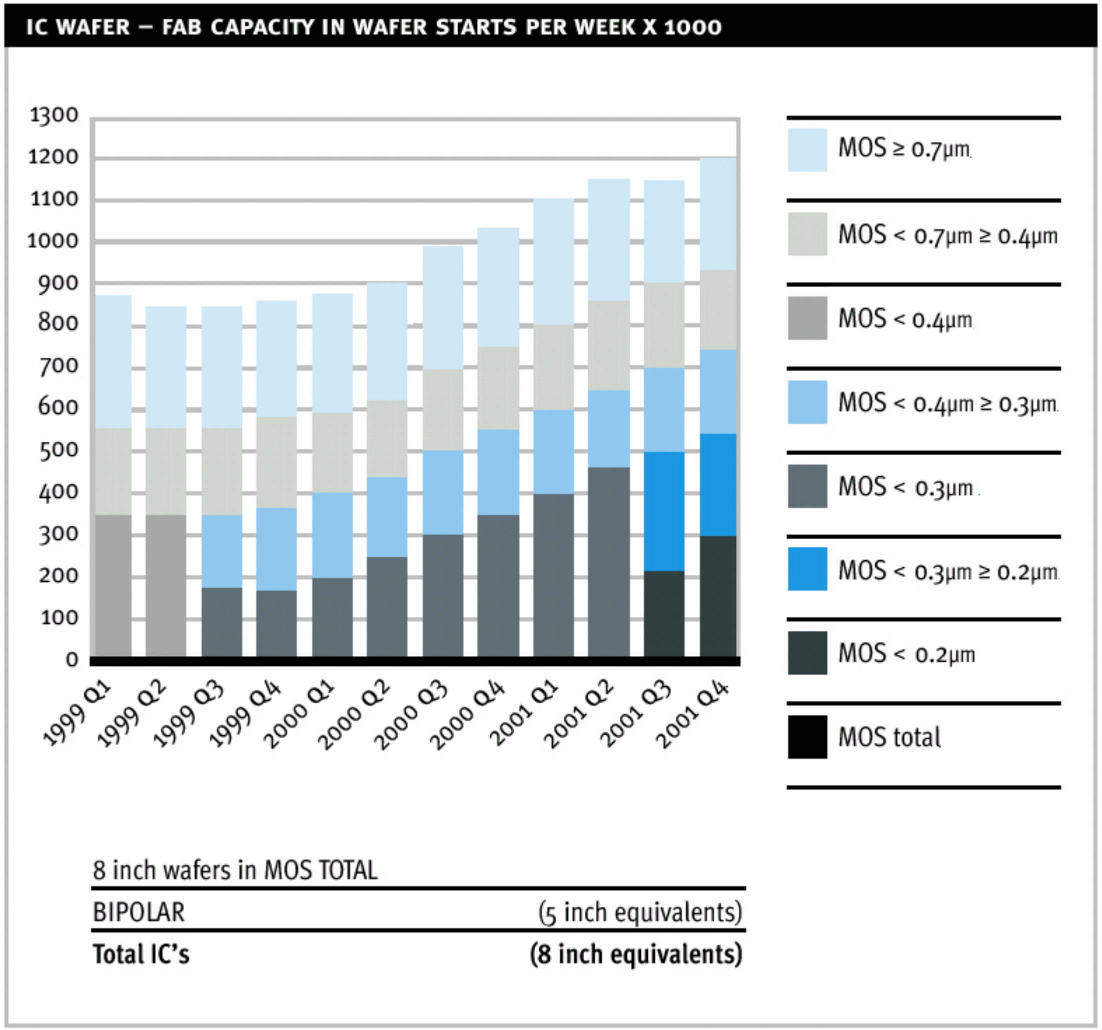


Results: Cumulative Assembly Cost





Worldwide Fab Capacity



- Assume 1 billion tags a day
- 100,000 dies/wafer
- 20% of world silicon capacity
- Fabs 15% idle today

Outline, Part II

- RFID and the Auto-ID Center
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  - A peek at the protocol
  - Security and Privacy Issues
  - Software
  - Vibration analysis
  - Silicon manufacturing

Conclusions

Physics and God