November, 2010

Technologies for Embedded Processors and Applications for Intelligent Control
Agenda

► Semiconductor Growth Trends & Drivers
► Building blocks for markets
► System complexity and technology adoption
► Summary
Three Trends Shaping Our Future

We See a
Healthier, Safer Population.

Health & Safety

We See a
Connected World
with Unlimited Possibilities.

Net Effect

We See a
Greener Planet.

Going Green
**Embedded Growth Drivers**

### Connected Intelligence
- Web 2.0
- Cloud Computing
- Social Network
- MediaNet

### Automotive Systems
- Media gateway
- Active & Predictive Safety
- Fuel efficiency

### Green Technology
- Smart Power
- Smart Grids
- Geo Engineering

### Health
- Aging
- Telemedicine
- Robotic surgery
Connected Intelligence

- Seamless integration of two distinct and independent technological innovations developed over the past decade
  - Internet
  - Mobile Communications
Drivers

- Mobile Data Traffic
  - 130% CAGR

- Emerging economies with low current penetration
  - > 50% CAGR outside N. America and Western Europe

- Business IP traffic
  - 1 laptop air card >> 15 smart phones
  - 1 Blackberry >> 30 cell phones

- Rich Broadband content
  - Video to PC, Video to TV, Video Communications, Peer to Peer
  - >85% of consumer and >50% of all IP traffic will be video

Global IP Traffic Growth

IP traffic will quintuple from 2008 to 2013
40% CAGR 2008-2013

Source: Cisco
Health

- Increase in longevity and quality of life desires
  - Wellness
    - Weight loss
    - Fitness
    - “Worried Well” vital sign monitoring
  - Disease Management
    - Chronic disease
    - Post trauma
    - Pre-Op

- Doctor/patient connectivity and quality of care driving telemedicine

Embedded Systems

Networks of Embedded Systems

Ubiquity: Large scale & dense deployment of embedded devices

Convergence of Networking, Personal Computing, Embedded Systems

Cyber Physical Systems
Heterogenous Devices & Networks

Tight Physical – Compute integration

Bluetooth®

Internet, GPRS, Phone

WLAN

Data Acquisition

Processing, Long term storage, analysis

Pre-Processing, local storage, user interface

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Going Green

► Increasing digital content in everyday life brings increased responsibility towards sustainable technology

► “Second Life residents don’t have bodies, but they do leave footprints” - blog post
System Complexity: Smart Energy Society

Electricity Grid

- **“Smart Infrastructure”**
  - Smart Grid
  - Microgeneration

- **“Smart Home”**
  - Smart Meter
  - Smart Appliances

- **“Smart Network”**
  - Real time market link
  - Supply power during demand peak

Digital Economy

- **Power Conversion**
  - Direct DC for primary power
  - Wide Band gap semiconductors for on board secondary power

- **System**
  - Core, Memory
  - Performance/Watt scalability

- **Peripherals**
  - Storage Network
  - Virtualization
Infrastructure Advances

Source: European Smart Grid Technology Platform, published by the EC, 2006
Automotive—Where it all comes together

“80% percent of innovation is electronic”

Regulation Driven: Safety, Green
Consumer Driven: Green, Comfort

Electronic cost as % of total car cost

Advanced Driver Assistance
Active-Pasive Safety
Green Powertrain
Radar / Vision
Telematics
Infotainment
Airbag
ABS / ESP
Body Electronics
Multiplexing
Electronic
Fuel Injection


Sources: Bosch, PSA, Freescale Strategy

Hybrid: 45%

45%

22%

30%

50%

15%

10%

5%

2.5%
System Complexity: Smart Highways Tomorrow: Vehicle – Road Network

- Sensor / Radar / Camera networks
- Vehicle – Road / Vehicle – Vehicle Communications
- Automated driving
- Predictive safety
- Platoon: Increased traffic density at higher speeds
Context Convergence: Infotainment

The need to stay connected

Consumer electronics penetrating the car

Wireless inside and out

Ethernet functionality

Automotive Infotainment Processor

- Ethernet Transport
- IP based applications
- SW download capability
- Multiple video streams incl. cameras
- HD video content

- DVD audio/video
- DVB-T
- Multi channel audio streaming

- 16 audio channels
- Navigation Graphics

Heads up displays

Entertainment

16 audio channels

Navigation Graphics

Context Convergence: Infotainment

Heads up displays

Entertainment
Safety Standards

► Increasing focus on functional safety standards (IEC 61508, ISO 26262)
  • Compliance to ISO26262 expected by 2011

► Functional safety standards have moved from a pure system level context to component level

► Address functional and architectural aspects in addition to procedural aspects

► EV / PHEV Safety considerations
  • High voltage isolation from passengers
  • Battery technology safety monitoring, e.g. Li-ion chemistry
  • Galvanic isolation – battery : chassis isolation sensing
Fault Tolerant / Resilient Design for Functional Safety

SRAM Variability and Reliability

Two-dimensional coding for SRAM yield improvement and soft error resilience

Reliable Systems Design at sub-65nm Technologies

Design Space Exploration for Safety-Critical Architectures

Collision
Avoidance
Steer by wire
Brake by wire
Airbag
Electronic Power Steering
Electronic Stability Control
Active Front Lighting
Precrash
Adaptive Cruise Control
Powertrain Technology Roadmap

EU fleet average CO₂ targets (g/km)

- 130
- 95
- ??

Demonstrators

H₂ infrastructure

Niche EV’s

Charging infrastructure

Mass Market EV Technology

Fuel Cell Vehicle

Fuel cell stack and H₂ storage cell breakthrough

Energy storage breakthrough

Plug-in Hybrid

Energy storage breakthrough

Full Hybrid

Micro / Mild Hybrid

IC engine and Transmission innovations (Diesel / Gasoline / Renewables

Vehicle Weight and Drag Reduction

Source: Ultra Low Carbon Vehicles in the UK, Department for transport, Gov’t of UK, published 04/2009
Powertrain Innovation: System Interdependencies

- Electric Vehicles
  - Advanced Batteries
  - Fuel Cell Technologies
- Hybrid Drive Innovations
  - Mild / Full / PHEV
- Advanced Combustion Engine Innovations: HCCI / DISC
  - Electric Drives
  - Power Electronics
  - Regenerative Brakes
  - Cylinder Pressure Sensors
  - Idle Auto Ignition
- Emissions Reduction
  - Exhaust After Treatment
  - Emissions Monitoring (Nox, PM)
- Systems Innovations
  - Starter Generator
  - Gearbox
- Design Innovations
  - Friction Reduction
  - Parasitic Losses Reduction
- Lower Cost
- Lower Emissions
- Higher Fuel Economy

Advanced
Combustion Engine
Innovations: HCCI / DISC

Emissions Reduction

Electric Vehicles

Systems Innovations

Design Innovations

Hybrid Drive Innovations
Mild / Full / PHEV
## HEV/EV Adoption Rate Factors

1. Government Regulation
2. Oil Prices
3. Battery Technology Breakthrough

### Hybrid & Electric Vehicle Market

- **Government Regulation**
- **Oil Prices**
- **Battery Technology Breakthrough**

#### HEV/EV Market

<table>
<thead>
<tr>
<th>Year</th>
<th>MCU (CAGR: 15% to 2020)</th>
<th>Power</th>
<th>Analog Gate Drivers</th>
<th>Total (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>48</td>
<td>568</td>
<td>58</td>
<td>675</td>
</tr>
<tr>
<td>2011</td>
<td>67</td>
<td>793</td>
<td>81</td>
<td>941</td>
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<tr>
<td>2012</td>
<td>82</td>
<td>968</td>
<td>99</td>
<td>1149</td>
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<td>2014</td>
<td>104</td>
<td>1256</td>
<td>129</td>
<td>1488</td>
</tr>
<tr>
<td>2016</td>
<td>125</td>
<td>1520</td>
<td>156</td>
<td>1801</td>
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<tr>
<td>2018</td>
<td>152</td>
<td>1840</td>
<td>188</td>
<td>2180</td>
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<tr>
<td>2020</td>
<td>177</td>
<td>2146</td>
<td>220</td>
<td>2542</td>
</tr>
</tbody>
</table>

*Data courtesy: Strategy Analytics, FSL Strategy*
EV / PHEV Semiconductor Market Opportunities

Battery Management System
55% CAGR*

DCDC CONVERTER
25% CAGR*

INVERTER
20% CAGR*

CHARGER
22% CAGR*

Alternator Regulator & Stop/Start
15% CAGR*

* : CAGR estimates to year 2015
Building blocks of success

Enabling Technology
- RF-LDMOS
- SOI
- Xtor Scaling
- RF Plastic Packaging
- Cu / low-k Interconnects
- HDTMOS
- Embedded Flash MCU

Circuits
- CF+
- StarCore
- 32bit µC
- Power Module

Systems
- We See a Greener Planet.
- We See a Healthier, Safer Population.
- We See a Connected World with Unlimited Possibilities.
Technology Innovation Vectors: Systems Focus

Massively Many Core

- Software
- Core architecture
- Interconnect Fabric
- Memory interface architecture

Design & Architecture

- Low power design
- Reconfigurable logic
- Resilient systems
- Multi physics simulation

Integration

- SiP / 3D Packaging
- Base station baseband
- Enhanced self-test
- Sensor Networks
Technology Implications: Massively Many core

Right Sized SMP cluster:
- 2-4 Cores with caches
- RAM
- Local interconnect fabric

Chip Scale Interconnection
Router

Chip scale interconnection
Circuits, Signaling and
Clocking solutions

CSI-Protocol Extensions
- Physical
- Data Link
- Routing Layer
- Coherency, Consistency,
  and Messaging

Future: Interconnect topology-aware Integration methodology
Technology Implications: Low power Femto Cells

- Seamless mobility
  - Increase in capacity and coverage
  - Across networks: Cellular / Wifi
  - Across Devices: Wireline / Cellular

- Scalable architecture

- 7:1 cost advantage for same coverage for femto compared to a macro

- Power savings over conventional base stations

- 4G Technology requirements
  - Multicore – computational load constrained by power requirements
  - Complex Software

Voice, data, video everywhere
- 70% of calls originate from indoor setting
- One device for in home and mobile
  - 20 somethings may never have a land line
### Technology Implications: Sensor Integration

- Autonomous Sensing Nodes
- Sensor Fusion
- Embedded Solutions

#### Board Level Integration

<table>
<thead>
<tr>
<th>Communication</th>
<th>Signal Conditioning &amp; Control</th>
<th>Software</th>
<th>MEMs Transducer</th>
<th>Solid State Transducer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Node</td>
<td>Analog</td>
<td>Manufacturing Calibration &amp; Trim</td>
<td>Bulk Micromachining</td>
<td>Integrated Radar Transeiver</td>
</tr>
<tr>
<td>Wired</td>
<td>CMOS Mixed-Signal ASIC 0.5 - 1.0(\mu)m</td>
<td>Embedded Control Low Level Apps</td>
<td>Poly-Silicon Surface Micromachining</td>
<td>Permalloy Magnetic</td>
</tr>
<tr>
<td>Wireless Sensor Networks</td>
<td>CMOS &amp; MCU 8bit 0.25(\mu)m</td>
<td>Navigation 3D Gesture 3(^{rd}) Party Apps</td>
<td>Hi-Aspect Ratio SM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CMOS &amp; MCU 32bit (\leq 0.18)(\mu)m</td>
<td></td>
<td>Hi-Aspect Ratio Hybrid Micromachining</td>
<td></td>
</tr>
</tbody>
</table>

#### Package Integration

- <1995
- 2000
- 2005
- 2010+

*Technologies:*
- Bulk Micromachining
- Poly-Silicon Surface Micromachining
- Hi-Aspect Ratio SM
- Hi-Aspect Ratio Hybrid Micromachining
- Integrated Radar Transeiver
- Permalloy Magnetic

*Techniques:*
- Autonomous Sensing Nodes
- Sensor Fusion
- Embedded Solutions

*Applications:*
- Wired
- Wireless Sensor Networks
- Manufacturing Calibration & Trim
- Embedded Control Low Level Apps
- Navigation 3D Gesture 3\(^{rd}\) Party Apps

*Transducers:*
- CMOS Mixed-Signal ASIC 0.5 - 1.0\(\mu\)m
- CMOS & MCU 8bit 0.25\(\mu\)m
- CMOS & MCU 32bit \(\leq 0.18\)\(\mu\)m
- Analog
- Independent Node
- Wired
- Wireless Sensor Networks

*Manufacturing Processes:*
- Bulk Micromachining
- Poly-Silicon Surface Micromachining
- Hi-Aspect Ratio SM
- Hi-Aspect Ratio Hybrid Micromachining

*Software and Control:*
- Manufacturing
- Calibration & Trim
- Embedded Control
- Low Level Apps
- Navigation
- 3D Gesture
- 3\(^{rd}\) Party Apps

*Applications:*
- Embedded Control
- Low Level Apps
- Manufacturing Calibration & Trim
- Navigation 3D Gesture 3\(^{rd}\) Party Apps

*Materials:*
- Permalloy
- Magnetic
- Integrated Radar Transeiver
- Solid State Transducer
System Design & Use Case: Smartbook / Tablet

3-axis sensor
Touch
eCompass
Light Sensor
Pressure

WiFi
WWAN
Bluetooth
Zigbee/RF4CE

$100
$200
$300
$400
$500
$600
$700
$800
$900

RF4CE
Sensor
Audio
PMIC
Apps Processor

CAGR 2010-14: 120%

Source: Custom Market Research Report

Apple iPad validates tablet market
Looking ahead: Automotive MCU + Flash

- Higher flash development cost for scaling with logic nodes for little benefit
  - FEOL cell scaling progressively more challenging to preserve logic performance
    - High density requirement drives aggressive cell scaling
  - Flash cell scaling limited by electrical & reliability requirements
    - Tunnel oxide thickness, parasitic coupling

- Alternative memory technologies still in nascent development with several options providing poor scalability
  - MRAM, CBRAM, RRAM, PCRAM

- SiP an increasing viable technology option for decoupling flash and MCU for optimum cost and performance
  - Partitioning SoC logic, analog, and NVM combination to achieve best cost and minimum number of interconnects is key
Embedded Systems Software Complexity

**Networking**
- Infrastructure complexity
- Increased capability: voice / text to Voice / video / multimedia - rich content
- Wireless

**Consumer**
- Analog world to digital domain
- Sophisticated power management, protection and user interface design

**Industrial**
- Sensing and networking proliferation; automation
- Energy conservation strategies

**Automotive**
- Infotainment
- Green focus
- Predictive safety – device network in and around the vehicle
Summary

► Embedded processing is an invaluable and invisible partner in driving key trends
  
  • Health and Safety
  • Going Green
  • Net Effect

► System complexity driving innovations shared across previously discrete product development
  
  • Safety standards leveraged in medical and automotive
  • Many core → massively many core for networking, automotive, and general purpose computing
  • Software complexity increasing in order to drive in seamless integration