Introduction to ASIC Design

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ELEC 5250/6250 – CAD of Digital ICs
Design & implementation of ASICs

Oops – Not these!
Application-Specific Integrated Circuit (ASIC)

- Developed for a specific application
- Not “general purpose”
# Progress of State of the Art

<table>
<thead>
<tr>
<th>Year</th>
<th>Integration Level</th>
<th># devices</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1938-46</td>
<td>Electromagnetic relays</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1943-54</td>
<td>Vacuum tubes</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1947-50</td>
<td>Transistor invented</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1950-61</td>
<td>Discrete components</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1961-66</td>
<td>SSI</td>
<td>10’s</td>
<td>Flip-flop</td>
</tr>
<tr>
<td>1966-71</td>
<td>MSI</td>
<td>100’s</td>
<td>Counter</td>
</tr>
<tr>
<td>1971-80</td>
<td>LSI</td>
<td>1,000’s</td>
<td>uP</td>
</tr>
<tr>
<td>1980-85</td>
<td>VLSI</td>
<td>100,000’s</td>
<td>uC</td>
</tr>
<tr>
<td>1985-90</td>
<td>ULSI*</td>
<td>1M</td>
<td>uC*</td>
</tr>
<tr>
<td>1990</td>
<td>GSI**</td>
<td>10M</td>
<td>SoC</td>
</tr>
<tr>
<td>2011</td>
<td>Intel Ten-Core Xeon</td>
<td>2.6G</td>
<td>CPU</td>
</tr>
<tr>
<td>2017</td>
<td>Nvidia GV100 Volta</td>
<td>21.1G</td>
<td>GPU</td>
</tr>
</tbody>
</table>
Moore’s Law (Gordon Moore – 1965)

“The complexity for minimum component costs has increased at a rate of roughly a factor of two per year

• ... over the short term this rate can be expected to continue, if not to increase.
• ... over the longer term, the rate of increase is a bit more uncertain
• ... no reason to believe it will not remain nearly constant for at least 10 years
• ... by 1975, #components per integrated circuit for minimum cost will be 65,000
• I believe that such a large circuit can be built on a single wafer.”
Moore’s Law Updated

40 Years of Microprocessor Trend Data

Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2015 by K. Rupp
System-on-Chip (SoC)

- An ASIC that packages basic computing components into a single chip.
- A SoC has most of the components to power a computer.
Advantages of SoC

- Higher performance benefiting from:
  - Less propagation delay since internal wires are shorter;
  - Less gate delay as internal transistors have lower electrical impedance;

- Power efficiency benefiting from:
  - Lower voltage required (typically < 2.0 volts) compared with external chip voltage (typically >3.0 volts);
  - Less capacitance;

- Lighter footprint:
  - Device size and weight is reduced;

- Higher reliability:
  - All encapsulated in a single chip package, less interference from the external world;

- Low cost:
  - Cost per unit is reduced since a single chip design can be fabricated in a large volumes.
Limitations of SoC

• Less flexibility

  • Unlike a PC or a laptop, which allows you to upgrade a single component, such as RAM or graphic card, a SoC cannot be easily upgraded after manufacture;

• Application Specific

  • Most SoCs are specified to particular applications thus they are not easily adapted to other applications.

• Complexity

  • A SoC design usually requires advanced skills compared with board-level development.
ARM-based SoC

- An basic ARM-based SoC usually consists of:
  - An ARM processor, such as Cortex-M0;
  - Advanced Microcontroller Bus Architecture (AMBA), e.g. AMBA3 or AMBA4;
  - Physical IPs (or peripherals) from ARM or third parties;
  - Additionally, some SoCs may have a more advanced architecture, such as multi-bus system with bus bridge, DMA engine, clock and power management, etc…
Apple “A8” SoC (System on Chip)

- Used in iPhone6 & iPhone6 Plus
- Manufactured by TSMC
  - 20nm, 89mm², 2B transistors
- Elements (unofficial):
  - 2 x ARM Cyclone ARMv8 64-bit cores running at 1.4GHz
  - IMG PowerVR 4-core GX6450 GPU
  - L1/L2/L3 SRAM caches
- Other devices
  - 1 GB LPDDR3 SDRAM
  - 16 to 128GB flash
  - Qualcomm MDM9625M LTE modem
  - M8 motion coprocessor (ARM Cortex M3 uC)
  - iSight camera
  - Near field communications chip (for Apple Pay)
  - User interface and sensors, accelerometers, gyro
  - Wi-Fi and Bluetooth
### SoC Example: Apple SoC Families

<table>
<thead>
<tr>
<th>SoC</th>
<th>Model No.</th>
<th>CPU</th>
<th>CPU ISA</th>
<th>Technology</th>
<th>Die size</th>
<th>Date</th>
<th>Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>APL0098</td>
<td>ARM11</td>
<td>ARMv6</td>
<td>90 nm</td>
<td>N/A</td>
<td>6/2007</td>
<td>iPhone, iPod Touch (1st gen.)</td>
</tr>
<tr>
<td>A4</td>
<td>APL0398</td>
<td>ARM Cortex-A8</td>
<td>ARMv7</td>
<td>45 nm</td>
<td>53.29 mm²</td>
<td>3/2010</td>
<td>iPad, iPhone 4, Apple TV (2nd gen.)</td>
</tr>
<tr>
<td>A5</td>
<td>APL0498</td>
<td>ARM Cortex-A9</td>
<td>ARMv7</td>
<td>45 nm</td>
<td>122.6 mm²</td>
<td>3/2011</td>
<td>iPad 2, iPhone 4S</td>
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<tr>
<td></td>
<td>APL2498</td>
<td>ARM Cortex-A9</td>
<td>ARMv7</td>
<td>32 nm</td>
<td>71.1 mm²</td>
<td>3/2012</td>
<td>Apple TV (3rd gen.)</td>
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<tr>
<td></td>
<td>APL7498</td>
<td>ARM Cortex-A9</td>
<td>ARMv7</td>
<td>32 nm</td>
<td>37.8 mm²</td>
<td>3/2013</td>
<td>AppleTV 3</td>
</tr>
<tr>
<td>A5X</td>
<td>APL5498</td>
<td>ARM Cortex-A9</td>
<td>ARMv7</td>
<td>45 nm</td>
<td>162.94 mm²</td>
<td>3/2012</td>
<td>iPad (3rd gen.)</td>
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<tr>
<td>A6</td>
<td>APL0598</td>
<td>Swift</td>
<td>ARMv7s</td>
<td>32 nm</td>
<td>96.71 mm²</td>
<td>9/2012</td>
<td>iPhone 5</td>
</tr>
<tr>
<td>A6X</td>
<td>APL5598</td>
<td>Swift</td>
<td>ARMv7s</td>
<td>32 nm</td>
<td>123 mm²</td>
<td>10/2012</td>
<td>iPad (4th gen)</td>
</tr>
<tr>
<td>A7</td>
<td>APL0698</td>
<td>Cyclone</td>
<td>ARMv8-A (64-bit)</td>
<td>28 nm</td>
<td>102 mm²</td>
<td>9/2013</td>
<td>iPhone 5S, iPad mini (2nd gen)</td>
</tr>
<tr>
<td></td>
<td>APL5698</td>
<td>Cyclone</td>
<td>ARMv8-A</td>
<td>28 nm</td>
<td>102 mm²</td>
<td>10/2013</td>
<td>iPad Air</td>
</tr>
<tr>
<td>A8</td>
<td>APL1011</td>
<td>Typhoon (dual-core)</td>
<td>ARMv8-A</td>
<td>20 nm</td>
<td>89 mm²</td>
<td>9/2014</td>
<td>iPhone 6, iPhone 6 plus</td>
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<tr>
<td>A8X</td>
<td>APL1012</td>
<td>Typhoon (triple-core)</td>
<td>ARMv8-A</td>
<td>20nm</td>
<td>128 mm²</td>
<td>10/2014</td>
<td>iPad Air 2</td>
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<tr>
<td>A9</td>
<td>APL0898</td>
<td>Twister (dual-core)</td>
<td>ARMv8-A</td>
<td>14nm FinFET 96 mm²</td>
<td>9/2015</td>
<td>iPhone 6S, 6S Plus iPad (2017)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>APL1022</td>
<td>Twister (dual-core)</td>
<td>ARMv8-A</td>
<td>16nm FinFET 104.5 mm²</td>
<td>11/2015</td>
<td>iPad Pro (12.9”, 9.7”)</td>
<td></td>
</tr>
<tr>
<td>A9X</td>
<td>APL1021</td>
<td>Twister (dual-core)</td>
<td>ARMv8-A</td>
<td>16nm FinFET 143.9 mm²</td>
<td>11/2015</td>
<td>iPad Pro (12.9”, 9.7”)</td>
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<tr>
<td>A10</td>
<td>APL1W24</td>
<td>Hurricane (quad-core)</td>
<td>ARMv8-A</td>
<td>16nm FinFET 125 mm²</td>
<td>9/2016</td>
<td>iPhone 7, 7 Plus</td>
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<tr>
<td>A10X</td>
<td>APL1071</td>
<td>Hurricane (hex-core)</td>
<td>ARMv8-A</td>
<td>10nm FinFET 96.4 mm²</td>
<td>6/2017</td>
<td>iPad Pro (10.5”, 12.9”)</td>
<td></td>
</tr>
</tbody>
</table>

T.I. smartphone reference design

Main SoC
SoC Example: NVIDIA Tegra 2

<table>
<thead>
<tr>
<th>Designer</th>
<th>NVIDIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2010</td>
</tr>
<tr>
<td>Processor</td>
<td>ARM Cortex-A9</td>
</tr>
<tr>
<td></td>
<td>(dual-core)</td>
</tr>
<tr>
<td>Frequency</td>
<td>Up to 1.2 GHz</td>
</tr>
<tr>
<td>Memory</td>
<td>1 GB 667 MHz LP-DDR2</td>
</tr>
<tr>
<td>Graphics</td>
<td>ULP GeForce</td>
</tr>
<tr>
<td>Process</td>
<td>40 nm</td>
</tr>
<tr>
<td>Package</td>
<td>12 x12 mm (Package on Package)</td>
</tr>
<tr>
<td>Used in tablets</td>
<td>Acer Iconia Tab A500</td>
</tr>
<tr>
<td></td>
<td>Asus Eee Pad Transformer</td>
</tr>
<tr>
<td></td>
<td>Motorola Xoom</td>
</tr>
<tr>
<td></td>
<td>Motorola Xoom Family Edition</td>
</tr>
<tr>
<td></td>
<td>Samsung Galaxy Tab 10.1</td>
</tr>
<tr>
<td></td>
<td>Toshiba Thrive</td>
</tr>
</tbody>
</table>

Intel® Core™ i7 Processor

**Performance/Features:**
- 8 processing threads via Intel® Hyper-Threading Technology (HT)
- 4 cores
- Turbo Mode operation
- Intel® QuickPath Interconnect (Intel® QPI) to Intel® X58 Express Chipset
- Integrated Memory Controller (IMC) – 3ch DDR3
- 7 more SSE4 instructions
- Overspeed Protection Removed

Intel’s Next Gen Computing Genius!
Automotive

**HARDWARE & SOFTWARE**

**POWER MANAGEMENT/BATTERY**
Manage energy, Regenerative braking, Burst usage, Solar

**SECURITY (Embedded)**
Secure processing, firmware, boot, OTA, data...

**PACKAGING**
Smaller, thinner, and simpler form factors

**IN-VEHICLE NETWORKING**
CAN, FlexRay, I2C, SCI, SPI

**IP**
Foundational, complex, specialized

**INTEGRATION**
NVM, RF, mixed-signal analog, sensors

**CONNECTIVITY (RF Tx and Rx)**
Local area, cellular, wired, USB

**MEMORY (Embedded, External)**
eFlash, eNVM, SRAM

**SENSOR FUSION**
Environmental, Crash / Safety, security...

**NAVIGATION**
GPS / GNSS / Location, Telematics

**STORAGE**
Order of magnitude increase

**COMPUTE (MCU, MPU, GPU, VPU)**
MHz thru GHz
Application Processors / Baseband
28SLP and 14LPP

PA Controller
180nm BCDLite & 180nm RF CMOS

Audio AMP
55nm BCDLite

Wi-Fi Transceivers
40nm LP

AMOLED Display Drivers
55nm DDI

RF Transceivers
65/55nm LPe-RF

Envelope Trackers
65/55nm BCDLite & 180nm RF CMOS

NFC Devices
40nm LP - eNVM

RF FEM
RF SOI & SiGe PA

PMICs
130/180nm BCDLite®

Accelerometers
MEMS
SoCs/ASICs for Internet of Things (IoT)

Why Now?

- ASICs are becoming:
  - Cheaper (<50c)
  - Smaller (<1mm²)
  - Lower power (µW)
  - Commoditised HW & SW

- Communication is growing faster (broadband)

- Socio-economic benefits
  - Globalisation
  - Automation & control
  - Mobility
  - Smart monitoring
  - Wide range of applications

Internet of Things Trend

- Safer/Smarter Automotive
- Smart Appliances
- Smart Farming
- Smart Lighting
- Industrial Internet Machine to Machine
- Fitness / Healthcare
- Portable and Wearable Electronics
- Resource Management
- Smart Home

Smart Electronics

Fitness / Healthcare

Portable and Wearable Electronics

Resource Management

Smart Home

Safer/Smarter Automotive

Smart Appliances

Smart Farming

Smart Lighting

Industrial Internet Machine to Machine
“IoT Things”
Basic Building Functional Blocks

- Sense
- Compute
- Control
- Store
- Communicate

Integrate into one ASIC/SoC