Integrated Electronics

Lecture Instructor: Randy Geiger
2133 Coover
rlgeiger@iastate.edu
294-7745

Course Web Site: http://class.ece.iastate.edu/ee330/

Lecture: MWF 9:100 0268 Carver

Lab:
Sec A  Tues  8:00 - 10:50
Sec B  Tues  11:00 – 1:50
Sec C  Wed  5:10 - 8:00
Sec D  Fri  8:00 - 10:50
Sec F  Mon  1:10 – 4:00

Labs all meet in Rm 2046 Coover

Labs start this week!

HW Assignment 1 has been posted and is due this Friday
Instructor Access:

• Office Hours
  – Open-door policy
  – MWF 11:00-11:45
    reserved for EE 330 students
  – By appointment

• Email
  – rlgeiger@iastate.edu
  – Include EE 330 in subject
Electronic Circuits in Industry Today

• Almost all electronic circuits are, at the most fundamental level, an interconnection of transistors and some passive components such as resistors, capacitors, and inductors

• For many years, electronic systems involved placing a large number of discrete transistors along with passive components on a printed circuit board

• Today, most electronic systems will not include any discrete transistors but often billions of transistors grouped together into a few clusters called integrated circuits

• In this course, emphasis will be placed on developing an understanding on how transistors operate and on how they can be combined to perform useful functions on an integrated circuit

• A basic understanding of semiconductor and fabrication technology and device modeling is necessary to use transistors in the design of useful integrated circuits
How Integrated Electronics will be Approached

- Semiconductor and Fabrication Technology
- Device Operation and Models
- Circuit Structures and Circuit Design
- CAD Tools
How Integrated Electronics will be Approached

After about four weeks, through laboratory experiments and lectures, the concepts should come together.
Topical Coverage

- Semiconductor Processes
- Device Models (Diode, MOSFET, BJT, Thyristor)
- Layout
- Simulation and Verification
- Basic Digital Building Blocks
- Behavioral Design and Synthesis
  - Standard cells
- Basic Analog Building Blocks
Topical Coverage Weighting

Fabrication Technology

Diodes

MOS Devices

Bipolar Devices (BJTs and Thyristors)

Logic Circuits

Small Signal Analysis and Models

Linear MOSFET and BJT Applications
Textbook:

CMOS VLSI Design – A Circuits and Systems Perspective
by Weste and Harris Addison Wesley/Pearson, 2011
- Fourth edition

Extensive course notes (probably over 1800 slides) will be posted but lecture material will not follow textbook on a section-by-section basis
Studying for this course:

• By focus on the broad concepts, the details should be rather easy to grasp

• Focusing on the details rather than broad concepts will make this course very difficult

• Read textbook as a support document even when lecture material is not concentrating on specific details in the book

• Although discussing homework problems with others on occasion is not forbidden, time will be best spent solving problems individually

• The value derived from the homework problems is not the grade but rather the learning that the problems are designed to provide
Grading Policy

3 Exams 100 pts each
1 Final 100 pts.
Homework 100 pts. total
Quizzes/Attendance 100 pts
Lab and Lab Reports 100 pts. total
Design Project 100 pts.

- A letter grade will be assigned based upon the total points accumulated
- Grade breaks will be determined based upon overall performance of the class
Attendance and Equal Access Policy

Participation in all class functions and provisions for special circumstances including special needs will be in accord with ISU policy.

Attendance of any classes or laboratories, turning in of homework, or taking any exams or quizzes is optional however grades will be assigned in accord with the described grading policy. No credit will be given for any components of the course without valid excuse if students choose to not be present or not to contribute. Successful demonstration of ALL laboratory milestones and submission of complete laboratory reports for ALL laboratory experiments to TA by deadline established by laboratory instructor is, however, required to pass this course.
Laboratory Safety

In the laboratory, you will be using electronic equipment that can cause serious harm or injuries, or even death if inappropriately used. Safety in the laboratory is critical.

Your TA will go through a laboratory safety procedure and ask you to certify that you have participated in the laboratory safety training.

Lab Safety guidelines are posted in all of the laboratories

Be familiar with the appropriate operation of equipment and use equipment only for the intended purpose and in the appropriate way

Be conscientious and careful with the equipment in the laboratory for your safety and for the safety of others in the laboratory
Due Dates and Late Reports

Homework assignments are due at the beginning of the class period on the designated due date. Late homework will be accepted without penalty up until 5:00 p.m. on the designated due date. Homework submitted after 5:00 p.m. will not be graded without a valid written excuse.

Laboratory reports are due at the beginning of the period when the next laboratory experiment is scheduled. Both a hard copy and a pdf file should be submitted. The file name on the pdf file should be of the following format:

EE330Lab1JonesP.pdf

where the lab number, your last name, and your first initial should be replaced as appropriate. The electronic version should be submitted to your TA and copied to the course instructor rlgeiger@iastate.edu

All milestones must be demonstrated to and recorded by the TA prior to turning in the laboratory report. Late laboratory reports will be accepted with a 30% penalty within one week of the original due date unless a valid written excuse is provided to justify a late report submission. Any laboratory reports turned in after the one-week late period will not be graded. The last laboratory report will be due one week after the scheduled completion of the experiment. Report on the final project will be due on Dec. 11.
Design Project

- Design project will focus on the design of an integrated circuit

- Opportunity will exist to have the integrated circuit fabricated through MOSIS

- Fabricated circuit will not be back from foundry until some time after class is over

- The cost of this fabrication would be many $ thousands if paid for privately
www.mosis.com
Reference Texts:

Fundamentals of Microelectronics  
by B. Razavi, Wiley, 2008

CMOS Circuit Design, Layout, and Simulation (3rd Edition)  

The Art of Analog Layout  
by Alan Hastings, Prentice Hall, 2005
Reference Texts:

Microelectronic Circuit Design (4th edition)
By Richard Jaeger and Travis Blalock,
McGraw Hill, 2010

Digital Integrated Circuits (2nd Edition)
by Jan M. Rabaey, Anantha Chandrakasan, Borivoje Nikolic, Prentice Hall, 2002

VLSI Design Techniques for Analog and Digital Circuits
Reference Texts:

Microelectronic Circuits (6th Edition)
by Sedra and Smith, Oxford, 2009

Other useful reference texts in the VLSI field:

Analog Integrated Circuit Design (2\textsuperscript{nd} edition)

Principles of CMOS VLSI Design
by N. Weste and K. Eshraghian, Addison Wesley, 1992

CMOS Analog Circuit Design (3\textsuperscript{rd} edition)
Other useful reference texts in the VLSI field:

Design of Analog CMOS Integrated Circuits
by B. Razavi, McGraw Hill, 1999

Design of Analog Integrated Circuits
by Laker and Sansen, McGraw Hill, 1994

Analysis and Design of Analog Integrated Circuits-Fifth Edition
Gray, Hurst, Lewis and Meyer, Wiley, 2009

Analog MOS Integrated Circuits for Signal Processing
Gregorian and Temes, Wiley, 1986

Digital Integrated Circuit Design
Untethered Communication Policy

Use them!
Hearing them ring represents business opportunity!

Please step outside of the room to carry on your conversations.
The Semiconductor Industry

(just the “chip” part of the business)

How big is it?

How does it compare to other industries?
How big is the semiconductor industry?

<table>
<thead>
<tr>
<th>Year</th>
<th>Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>$25B</td>
</tr>
<tr>
<td>1990</td>
<td>$50B</td>
</tr>
<tr>
<td>1994</td>
<td>$100B</td>
</tr>
<tr>
<td>2004</td>
<td>$200B</td>
</tr>
<tr>
<td>2010</td>
<td>$304B</td>
</tr>
<tr>
<td>2014</td>
<td>$325B  (projected)</td>
</tr>
<tr>
<td>2016</td>
<td>$350B  (projected)</td>
</tr>
</tbody>
</table>

Semiconductor sales do not include the sales of the electronic systems in which they are installed and this marked is much bigger !!
The Semiconductor Industry

How big is it?

How does it compare to Iowa-Centric Commodities?
Iowa-Centric Commodities
Iowa-Centric Commodities

In the United States, Iowa ranks:

- First in Corn production
- First in Soybean production
- First in Egg production
- First in Hog production
- Second in Red Meat production

Iowa-Centric Commodities

Corn

Beans
Agricultural Commodities are a Major Part of the Iowa Economy
# Value of Agricultural Commodities

## Corn Production

<table>
<thead>
<tr>
<th></th>
<th>Bushels (Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa</td>
<td>2.2</td>
</tr>
<tr>
<td>United States</td>
<td>12</td>
</tr>
<tr>
<td>World</td>
<td>23</td>
</tr>
</tbody>
</table>

## Soybean Production

<table>
<thead>
<tr>
<th></th>
<th>Bushels (Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa</td>
<td>0.34</td>
</tr>
<tr>
<td>United States</td>
<td>3.1</td>
</tr>
<tr>
<td>World</td>
<td>8.0</td>
</tr>
</tbody>
</table>
Based upon Jan 9, 2015 closing markets in Boone Iowa

Corn

AUG 2015  3.33

Soybeans

AUG 2015  9.01
## Value of Agricultural Commodities

(Based upon commodity prices in Boone Iowa on Aug 25 2015)

(simplifying assumption: value constant around world)

### Corn Production

<table>
<thead>
<tr>
<th></th>
<th>Bushels (Billions)</th>
<th>Value (Billion Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa</td>
<td>2.2</td>
<td>$7.3</td>
</tr>
<tr>
<td>United States</td>
<td>12</td>
<td>$40</td>
</tr>
<tr>
<td>World</td>
<td>23</td>
<td>$77</td>
</tr>
</tbody>
</table>

### Soybean Production

<table>
<thead>
<tr>
<th></th>
<th>Bushels (Millions)</th>
<th>Value (Billion Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa</td>
<td>340</td>
<td>$3.1</td>
</tr>
<tr>
<td>United States</td>
<td>3,100</td>
<td>$29</td>
</tr>
<tr>
<td>World</td>
<td>8,000</td>
<td>$72</td>
</tr>
</tbody>
</table>

World 2014 semiconductor sales of $325B about 220% larger than value of total corn and soybean production today!

Semiconductor sales has averaged about 300% larger than value of total corn and soybean production for much of past two decades!
The Semiconductor Industry

How big is it?
About $325B/Year and growing

How does it compare to Iowa-Centric Commodities?
Larger than major agricultural commodities (2X to 3X)

The semiconductor industry is one of the largest sectors in the world economy and continues to grow
How is the semiconductor industry distributed around the world?

<table>
<thead>
<tr>
<th>Rank 2013</th>
<th>Rank 2012</th>
<th>Company</th>
<th>Country of origin</th>
<th>Revenue (million $ USD)</th>
<th>2013/2012 changes</th>
<th>Market share</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Intel Corporation(1)</td>
<td>USA</td>
<td>46 960</td>
<td>-1.0%</td>
<td>14.8%</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Samsung Electronics(2)</td>
<td>South Korea</td>
<td>33 456</td>
<td>+7.0%</td>
<td>10.5%</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Qualcomm</td>
<td>USA</td>
<td>17 341</td>
<td>+31.6%</td>
<td>5.5%</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>Micron Technology(3)</td>
<td>USA</td>
<td>14 168</td>
<td>+109.2%</td>
<td>4.5%</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>SK Hynix</td>
<td>South Korea</td>
<td>13 335</td>
<td>+48.7%</td>
<td>4.2%</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>Toshiba Semiconductor</td>
<td>Japan</td>
<td>12 459</td>
<td>+11.9%</td>
<td>3.9%</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>Texas Instruments</td>
<td>USA</td>
<td>11 379</td>
<td>-5.5%</td>
<td>3.6%</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>Broadcom</td>
<td>USA</td>
<td>8 121</td>
<td>+3.5%</td>
<td>2.6%</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>STMicroelectronics</td>
<td>France, Italy</td>
<td>8 076</td>
<td>-4.9%</td>
<td>2.5%</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>Renesas Electronics(4)</td>
<td>Japan</td>
<td>7 822</td>
<td>-15.3%</td>
<td>2.5%</td>
</tr>
<tr>
<td>11</td>
<td>13</td>
<td>Infineon Technologies</td>
<td>Germany</td>
<td>5 096</td>
<td>+5.7%</td>
<td>1.6%</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>AMD</td>
<td>USA</td>
<td>5 076</td>
<td>-4.2%</td>
<td>1.6%</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
<td>NXP</td>
<td>Netherlands</td>
<td>4 658</td>
<td>+13.2%</td>
<td>1.5%</td>
</tr>
<tr>
<td>14</td>
<td>18</td>
<td>MediaTek</td>
<td>Taiwan</td>
<td>4 434</td>
<td>+32.1%</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

http://en.wikipedia.org/wiki/Semiconductor_sales_leaders_by_year#Ranking_for_year_2013
How is the semiconductor industry distributed around the world?

<table>
<thead>
<tr>
<th>Rank</th>
<th>Rank</th>
<th>Company</th>
<th>Country</th>
<th>Revenue</th>
<th>Growth</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>11</td>
<td>Sony</td>
<td>Japan</td>
<td>4 394</td>
<td>-28.1%</td>
<td>1.4%</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>Freescale Semiconductor</td>
<td>USA</td>
<td>3 958</td>
<td>+5.8%</td>
<td>1.2%</td>
</tr>
<tr>
<td>17</td>
<td>15</td>
<td>NVIDIA</td>
<td>USA</td>
<td>3 612</td>
<td>-5.6%</td>
<td>1.1%</td>
</tr>
<tr>
<td>18</td>
<td>19</td>
<td>Marvell Technology Group</td>
<td>USA</td>
<td>3 281</td>
<td>+3.6%</td>
<td>1.0%</td>
</tr>
<tr>
<td>19</td>
<td>22</td>
<td>ON Semiconductor</td>
<td>USA</td>
<td>2 740</td>
<td>-4.5%</td>
<td>0.9%</td>
</tr>
<tr>
<td>20</td>
<td>23</td>
<td>Analog Devices</td>
<td>USA</td>
<td>2 677</td>
<td>+0.2%</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

http://en.wikipedia.org/wiki/Semiconductor_sales_leaders_by_year#Ranking_for_year_2013
# Investment in New Technology

## 2013 Worldwide Semiconductor R&D Spending Leaders
(Companies with ≥$1 Billion in Spending)

<table>
<thead>
<tr>
<th>Rank</th>
<th>2012 Rank</th>
<th>Company</th>
<th>Region/Country</th>
<th>Type</th>
<th>2012 Sales ($M)</th>
<th>2012 R&amp;D ($M)</th>
<th>R&amp;D/Sales</th>
<th>2013 Sales ($M)</th>
<th>2013 R&amp;D ($M)</th>
<th>R&amp;D/Sales</th>
<th>13/12 R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Intel</td>
<td>Americas</td>
<td>IDM</td>
<td>49,114</td>
<td>10,148</td>
<td>21%</td>
<td>48,321</td>
<td>10,611</td>
<td>22%</td>
<td>5%</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Qualcomm</td>
<td>Americas</td>
<td>Fabless</td>
<td>13,177</td>
<td>2,655</td>
<td>20%</td>
<td>17,211</td>
<td>3,395</td>
<td>20%</td>
<td>28%</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Samsung</td>
<td>South Korea</td>
<td>IDM</td>
<td>32,251</td>
<td>2,765</td>
<td>9%</td>
<td>34,378</td>
<td>2,820</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>Broadcom</td>
<td>Americas</td>
<td>Fabless</td>
<td>7,793</td>
<td>2,318</td>
<td>30%</td>
<td>8,219</td>
<td>2,486</td>
<td>30%</td>
<td>7%</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>ST</td>
<td>Europe</td>
<td>IDM</td>
<td>8,364</td>
<td>2,413</td>
<td>29%</td>
<td>8,044</td>
<td>1,816</td>
<td>23%</td>
<td>-25%</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>TSMC</td>
<td>Taiwan</td>
<td>Foundry</td>
<td>16,951</td>
<td>1,370</td>
<td>8%</td>
<td>19,850</td>
<td>1,623</td>
<td>8%</td>
<td>18%</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>Toshiba</td>
<td>Japan</td>
<td>IDM</td>
<td>11,217</td>
<td>1,710</td>
<td>15%</td>
<td>11,958</td>
<td>1,560</td>
<td>13%</td>
<td>-9%</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>TI</td>
<td>Americas</td>
<td>IDM</td>
<td>12,081</td>
<td>1,877</td>
<td>16%</td>
<td>11,475</td>
<td>1,522</td>
<td>13%</td>
<td>-19%</td>
</tr>
<tr>
<td>9</td>
<td>13</td>
<td>Micron</td>
<td>Americas</td>
<td>IDM</td>
<td>8,002</td>
<td>909</td>
<td>11%</td>
<td>14,433</td>
<td>1,487</td>
<td>10%</td>
<td>64%</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>Renesas</td>
<td>Japan</td>
<td>IDM</td>
<td>9,314</td>
<td>1,901</td>
<td>20%</td>
<td>7,975</td>
<td>1,343</td>
<td>17%</td>
<td>-29%</td>
</tr>
</tbody>
</table>

Top 10 Total: 168,264, 28,066, 16.7%, 181,864, 28,663, 15.8%, 2%

Source: Company reports, IC Insights

Applications of Electronic Devices

- Communication systems
- Computation systems
- Instrumentation and control
- Signal processing
- Biomedical devices
- Automotive
- Entertainment
- Military
- Many-many more

Applications often incorporate several classical application areas

Large number (billions) of devices (transistors) in many applications

Electronic circuit designers must understand system operation to provide useful electronic solutions
Automotive industry seeking electronic solutions to four main issues

Part 1
Electronics to account for 40% of automotive production costs by 2015

The proportion of electronic components used in motor vehicles has been increasing steeply in recent years. In fact, many industry observers expect electronic components to account for 40% of total car production costs in the near future. Automakers are already relying more heavily on electronics technology, with electronic components making up 10-15% of the total production cost of a 2007-model compact car such as the Toyota Corolla, for 20-30% of the cost of luxury models like Lexus-brand cars, and for around 50% in the case of hybrid electric vehicles (HEVs) such as the Toyota Prius. Electronic components currently comprise some 20-30% of total costs for all car categories, and this figure is expected to reach 40% or so by 2015. Roughly speaking, materials and components represent 70% of total car production costs, while labor costs account for 15% and miscellaneous expenses for the remaining 15%. If present trends continue, by 2015 electronic component costs will comprise the majority of materials/components costs.
An example of electronic opportunities

Consider High Definition Television (HDTV)

Video:

Frame size: 1920 x 1080 pixels (one HDTV frame size)
Frame rate: 24 frames/second (one HDTV frame rate)

Pixel Resolution: 8 bits each RGB plus 8 bits alpha (32 bits/pixel) (no HDTV standard)

RAW (uncompressed) video data requirements: \(1920 \times 1080 \times 24 \times 32 = 1.59 \text{ G bits/sec}\)

Audio:

Sample rate: 192 K SPS (44.1 more common)
Resolution: 24 bits (16 bits or less usually adequate)
Number of Channels: 2 (Stereo)

RAW (uncompressed) audio data requirements: \(192 \times 24 \times 2 = 9.2 \text{ Mbits/sec}\)

- RAW video data rate approximately 170X the RAW audio data rate
- Are RAW video data rates too large to be practical ??
How much would it cost to download a 2-hour HDTV “movie” using RAW audio and video on a Verizon Smart Phone today?

Verizon Data Plan (after 1.5GB included in monthly fee) $15/GB

RAW (uncompressed) video data requirements: \((1920\times1080)\times24\times32 = 1.59\) G bits/sec

RAW (uncompressed) audio data requirements: \(192\times24\times2 = 9.2\) Mbits/sec

Total bits: \(1.5992\times60\times120\) Gb = 11,514Gb

Total bytes: \(1.5992\times60\times120/8\) GB = 1,439GB

Total cost: $21,589

- Some are actually using 60 fps and 64 bits/pixel
- Moving audio and video data is still expensive and still challenging!
- Be careful about what you ask for because you can often get it!

What can be done to reduce these costs?
An example of electronic opportunities

Consider High Definition Television (HDTV)

Video:

RAW (uncompressed) video data requirements: \((1920 \times 1080) \times 24 \times (32) = 1.59 \text{ G bits/sec}\)

Audio:

RAW (uncompressed) audio data requirements: \(192 \text{K} \times 24 \times 2 = 9.2 \text{ Mbits/sec}\)

Compressive video coding widely used to reduce data speed and storage requirements

- HDTV video streams used by the broadcast industry are typically between 14MB/sec and 19MB/sec (a compressive coding of about 14:1)

- But even with compression, the amount of data that must be processed and stored is very large

- Large electronic circuits required to gather, process, record, transmit, and receive data for HDTV
How much would it cost to download a 2-hour HDTV “movie” using compressed audio and video on a Verizon Smart Phone today? Assume total signal compressed to 14MB/sec.

Verizon Data Plan of May 2014 (after 1.5GB included in monthly fee) $15/GB

Total bytes: 14MBx60x120 GB = 101GB

Total cost: $1,515

Moving audio and video data is still expensive and still challenging!

(Verizon data plan of Aug 2015 is $7.50/GB from 1G to 3G increment)
Challenge to Students

- Become aware of how technology operates
- Identify opportunities where electronics technology can be applied
- Ask questions about how things operate and why
Selected Semiconductor Trends

- Microprocessors
- DRAMS
- FPGA
## Microprocessors

**Main article:** microprocessor chronology

<table>
<thead>
<tr>
<th>Processor</th>
<th>Transistor count</th>
<th>Date of introduction</th>
<th>Manufacturer</th>
<th>Process</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel 4004</td>
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<tr>
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<td>Intel</td>
<td>3 μm</td>
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<td>3 μm</td>
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<tr>
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<td>Intel</td>
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<thead>
<tr>
<th>Processor</th>
<th>Transistor count</th>
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<th>Manufacturer</th>
<th>Process</th>
<th>Area</th>
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<td>65 nm</td>
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### GPUs

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<th>Manufacturer</th>
<th>Process</th>
<th>Area</th>
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<td>G80</td>
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<td>NVIDIA</td>
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<td>RV770</td>
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<td>RV850</td>
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<td>NVIDIA</td>
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<td>RV870</td>
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### FPGA

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<td>Xilinx</td>
<td>90 nm</td>
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<td>Virtex-5</td>
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<td>Xilinx</td>
<td>65 nm</td>
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<tr>
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<td>2008</td>
<td>Altera</td>
<td>40 nm</td>
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</table>
Today!

Processor

Quad-Core Intel® Core i7 Processor Up to 3.4GHz in 32nm CMOS
Power Dissipation: 95 watts
Processor

- 8-core or 18-core Broadwell Intel® Core M Processor in 14nm CMOS
- Intel Tic-Toc product (“Toc” from 22nm Haswell processor)

Power Dissipation: 4.9 watts
Figure 1. Microprocessor complexity (transistor count) over time

From ISSCC 2010 Summary
Figure 2. Microprocessor power consumption over time

From ISSCC 2010 Summary
Figure 3. Microprocessor clock frequency over time

From ISSCC 2010 Summary
Figure 4. Microprocessor core count over time
Figure 7.1: Actual and predicted evolution of circuit complexity in DRAMs and microprocessors.
## DDR3 SDRAM Part Catalog

**Part Catalog Tips**
- **Filter by Attribute Values:** Select appropriate attribute values from the column drop down (🔍) or
- **Add or Remove Values:** Select or deselect values from the column drop down (🔍) and click “Up
- **Compare Parts:** Select the checkboxes and click “Compare”
- **Reset Values:** Click “Reset” to reset filtered values
- **Export to Spreadsheet:** To download part table to a spreadsheet, select “Export to Spreadsheet”

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Density</th>
<th>Part Status</th>
<th>RoHS</th>
<th>Depth</th>
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<th>Voltage</th>
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<tr>
<td>MT4J128M16HA-107G</td>
<td>2Gb</td>
<td>Sampling</td>
<td>Yes</td>
<td>128Mb</td>
<td>x16</td>
<td>1.5V</td>
</tr>
<tr>
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<td>Production</td>
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<td>128Mb</td>
<td>x16</td>
<td>1.5V</td>
</tr>
<tr>
<td>MT4J128M16HA-125G</td>
<td>2Gb</td>
<td>Sampling</td>
<td>Yes</td>
<td>128Mb</td>
<td>x16</td>
<td>1.5V</td>
</tr>
<tr>
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## Memory Trends

### Samsung Memory Product List

**Memory > Computing DRAM > DDR3 > Component**

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<thead>
<tr>
<th>Partnumber</th>
<th>Density</th>
<th>Organization</th>
<th>Voltage(V)</th>
<th>Speed</th>
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<tr>
<td>K4B4G0446A</td>
<td>4G bit</td>
<td>1Gx4</td>
<td>1.5,1.35</td>
<td>F8,H9,K0</td>
</tr>
<tr>
<td>K4B4G0846A</td>
<td>4G bit</td>
<td>512Mx8</td>
<td>1.5,1.35</td>
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<tr>
<td>K4B2G0446D</td>
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<td>512Mx4</td>
<td>1.5,1.35</td>
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<tr>
<td>K4B2G0846D</td>
<td>2G bit</td>
<td>256Mx8</td>
<td>1.5,1.35</td>
<td>F8,H9,K0,MA</td>
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<tr>
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<td>2G bit</td>
<td>512Mx4</td>
<td>1.5,1.35</td>
<td>F8,H9,K0</td>
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<tr>
<td>K4B2G0846C</td>
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<td>256Mx8</td>
<td>1.5,1.35</td>
<td>F8,H9,K0</td>
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<td>F8,H9,K0</td>
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<td>2G bit</td>
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<td>1.5</td>
<td>F8,H9,K0</td>
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</table>
NAND Flash Memory: Significant developments in NAND flash memory over the past few years, resulting in high-density, low-power, and low-cost storage solutions that are enabling the replacement of traditional hard-disk storage with solid-state disks (SSDs). Figure 5 shows the observed trend in NAND flash capacities presented at ISSCC in the past 12 years. Note that in 2010, the reduction in process feature sizes, coupled with advanced multi-level cell (MLC) techniques have yielded a 32Gb/chip capacity in a 32nm technology with 2bit/cell operation.
Figure 8. Data Rate Trend Chart

From ISSCC 2010 Summary
Selected Semiconductor Trends

- **Microprocessors**
  - State of the art technology is now 14nm with over 5 Billion transistors on a chip

- **DRAMs**
  - State of the art is now 4G bits on a chip which requires somewhere around 4.5 Billion transistors

- **FPGA**
  - FPGAs currently have over 7 Billion transistors and are growing larger

Device count on a chip has been increasing rapidly with time, device size has been decreasing rapidly with time and speed/performance has been rapidly increasing
Moore’s Law

From Webopedia

The observation made in 1965 by Gordon Moore, co-founder of Intel, that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data density has doubled approximately every 18 months, and this is the current definition of Moore's Law, which Moore himself has blessed. Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades.
Feature Size

The feature size of a process generally corresponds to the minimum lateral dimensions of the transistors that can be fabricated in the process.

- Bounding region often a factor of 10 or more larger than area of transistor itself
- This along with interconnect requirements and sizing requirements throughout the circuit create an area overhead factor of 10x to 100x
Moore’s Law

(from Wikipedia)

Moore's law is the **empirical** observation that the **complexity** of **integrated circuits**, with respect to minimum component cost, doubles every 24 months[1]. It is attributed to **Gordon E. Moore[2]**, a co-founder of **Intel**.

- Often misinterpreted or generalized
- Many say it has been dead for several years
- Many say it will continue for a long while
- Not intended to be a long-term prophecy about trends in the semiconductor field

Device scaling, device count, circuit complexity, … will continue to dramatically improve for the foreseeable future !!
ITRS Technology Predictions

ITRS 2004 Supply Voltage Predictions

Volts

YEAR

Analog

Digital
ITRS Technology Predictions

Minimum ASIC Gate Length

YEAR
Length in nm

YEAR
Challenges

- Managing increasing device count
- Short lead time from conception to marketplace
- Process technology advances
- Device Performance Degradation
- Increasing variability
- Increasing pressure for cost reduction
- Power Dissipation
Future Trends and Opportunities

• Is there an end in sight?

No! But the direction the industry will follow is not yet known and the role semiconductor technology plays on society will increase dramatically!

• Will engineers trained in this field become obsolete at mid-career?

No! Engineers trained in this field will naturally evolve to support the microelectronics technology of the future. Integrated Circuit designers are now being trained to efficiently manage enormous levels of complexity and any evolutionary technology will result in even larger and more complexity systems with similar and expanded skills being required by the engineering community with the major changes occurring only in the details.
Future Trends and Opportunities

• Will engineers trained in this field be doing things the same way as they are now at mid-career?

No! There have been substantive changes in approaches every few years since 1965 and those changes will continue. Continuing education to track evolutionary and revolutionary changes in the field will be essential to remain productive in the field.

• What changes can we expect to see beyond the continued geometric growth in complexity (capability) ?

That will be determined by the creativity and marketing skills of those who become immersed in the technology. New “Gordon Moores”, “Bill Gates” and “Jim Dells” will evolve.
Creation of Integrated Circuits

Most integrated circuits are comprised of transistors along with a small number of passive components and maybe a few diodes.

This course will focus on understanding how transistors operate and on how they can be interconnected and possibly combined with a small number of passive components to form useful integrated circuits.
End of Lecture 1