EE 330 Spring 2019
Integrated Electronics

MWF 9:00-9:50 am, Bessey 2226

Lecture Instructors:
Office: 2134 Coover Hall
Phone: 294-6277 (voice)
E-mail: djchen@iastate.edu

Course Web Site: http://class.ece.iastate.edu/djchen/ee330/2019S

TA information:

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Bertucci, Anthony V bertucci@iastate.edu
TBA
TBA

Labs all meet in Rm 2046 Coover

Labs start this week !

HW Assignment 1 has been posted and is due this Friday

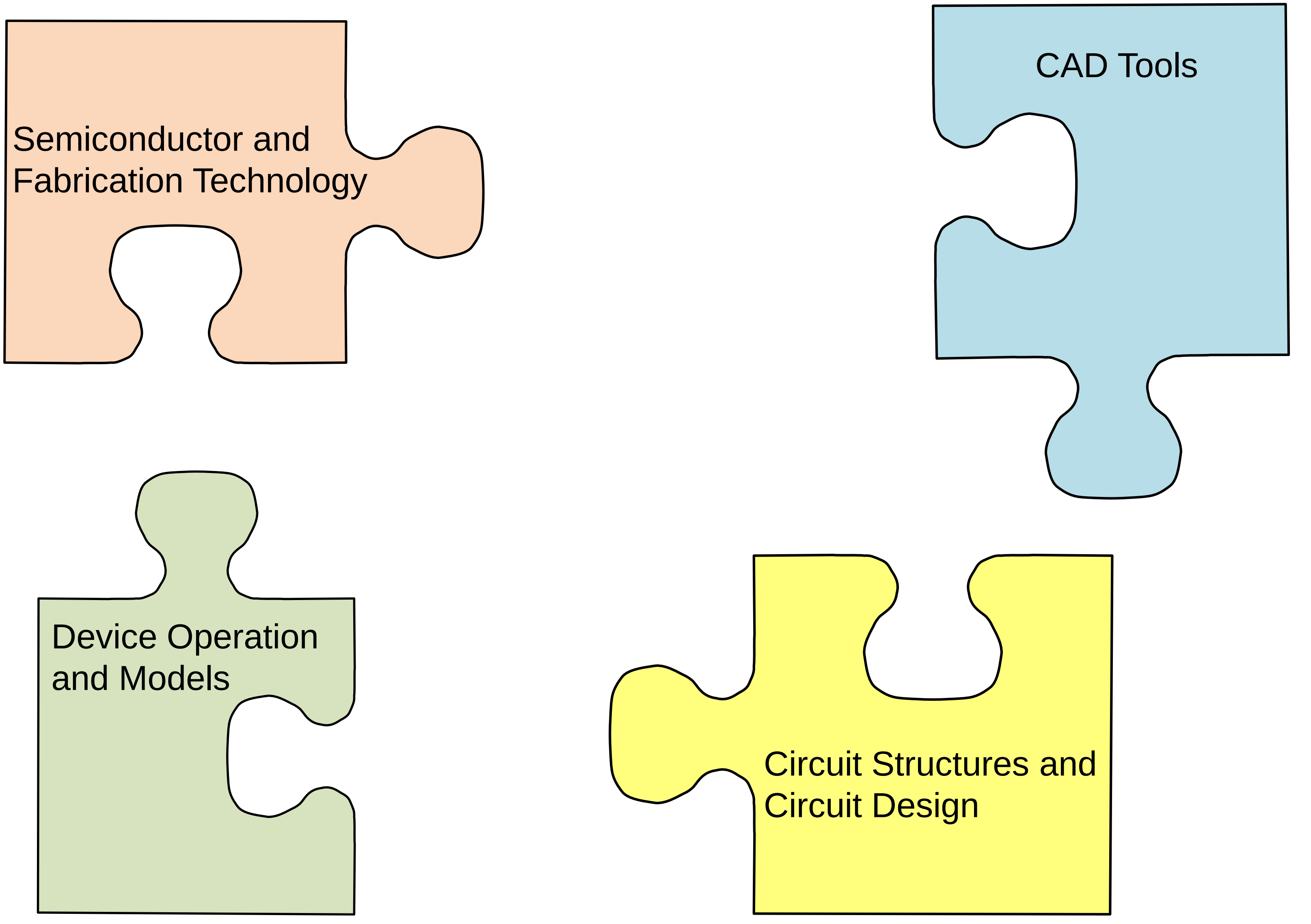
Catalog Description

E E 330. Integrated Electronics. (Same as Cpr E 330.) (3-3) Cr. 4. F.S. *Prereq:* 201, credit or enrollment in EE 230, Cpr E 210. Semiconductor technology for integrated circuits. Modeling of integrated devices including diodes, BJTs, and MOSFETs. Physical layout. Circuit simulation. Digital building blocks and digital circuit synthesis. Analysis and design of analog building blocks. Laboratory exercises and design projects with CAD tools and standard cells.

Electronic Circuits in Industry Today

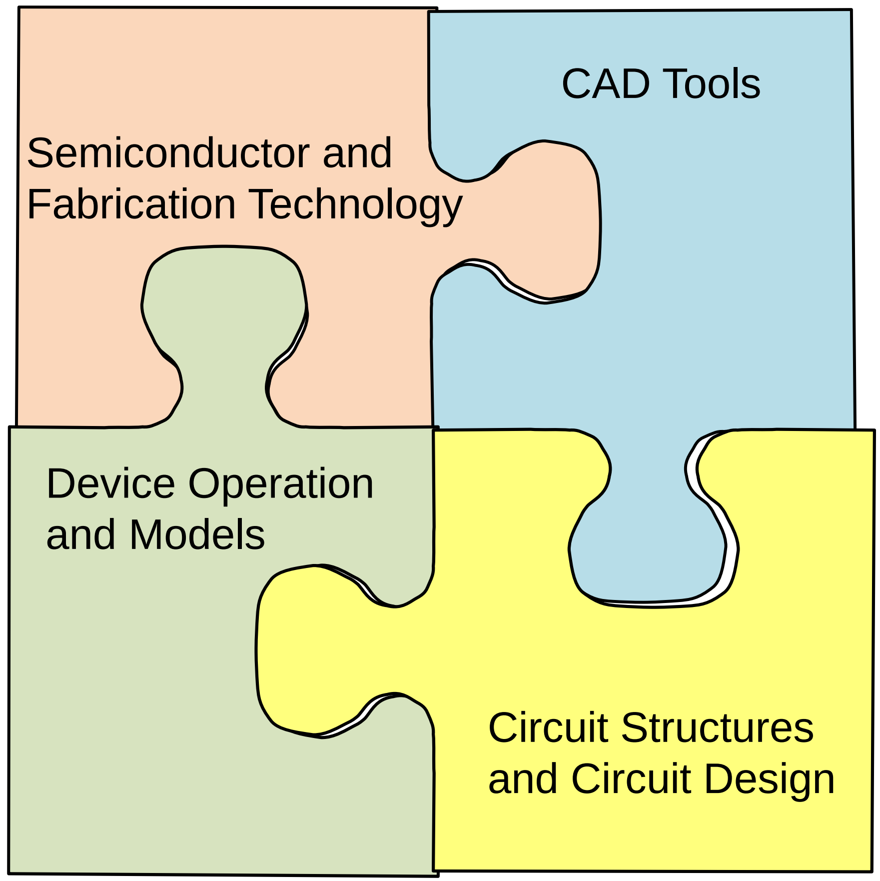
- Almost all electronic circuits are, at the most fundamental level, an interconnection of transistors and some passive components such as resistors, capacitors, and inductors
- For many years, electronic systems involved placing a large number of discrete transistors along with passive components on 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, on how they can be combined to perform useful functions on an integrated circuit, and on designing basic analog and digital integrated circuits
- 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



How Integrated Electronics will be Approached

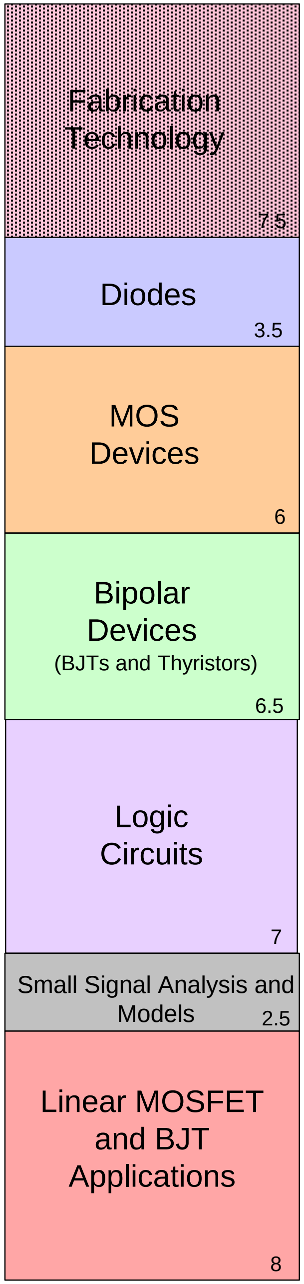
After about four weeks, through laboratory experiments and lectures, the concepts should come together



Topical Coverage

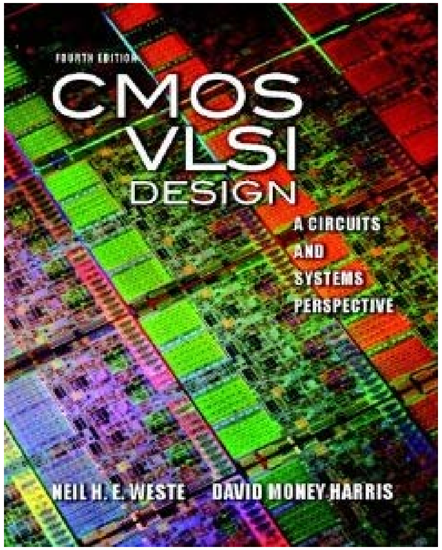
- Semiconductor Processes
- Device Models (Diode,MOSFET,BJT, Thyristor)
- Layout
- Simulation and Verification
- Basic Digital Building Blocks
- Behavioral Design and Synthesis
  - Standard cells
- Basic Analog Building Blocks

Topical Coverage Weighting



Textbook:

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



- Detailed Course Notes

  Extensive course notes (probably over 1800 slides) will be posted

Lecture material will not follow textbook on a section-by-section basis

Grading Policy

3 Exams	10% each
1 Final	15%
Homework	15%
Quizzes/Attendance	15%
Lab and Lab Reports	15%
Design Project	10%

A is >=90%
Each lower grade is 5% lower
Lower than C- is F

Studying for this course:

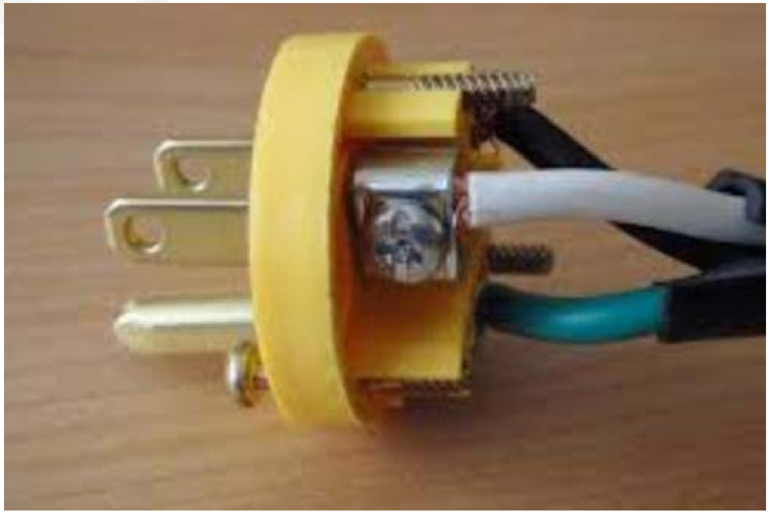
- By focusing on the broad concepts, the details should be rather easy to grasp
- Focusing on the details rather than broad concepts will make this course very difficult
- Read textbook as a support document even when lecture material is not concentrating on specific details in the book
- Although discussing 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

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



Laboratory Safety

- In the laboratory, you will be using electronic equipment that can cause serious harm or injuries, or even death if inappropriately used. However, if used in the appropriate way, the risk of harm is very low. 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
- Use common-sense as a guide when working 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 unless notified to the contrary in class. 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 at 5:00 p.m. on Friday Dec 7.

Design Project

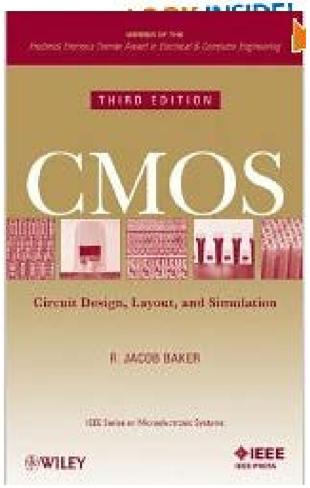
- Design project will focus on the design of an integrated circuit
- Opportunity will exist to have the integrated circuit fabricated through MOSIS
- Fabricated circuit will not be back from foundry until some time after class is over
- The cost of this fabrication would be many $ thousands if paid for privately
- The final project will be culminated with an oral presentation and a written report

www.mosis.com

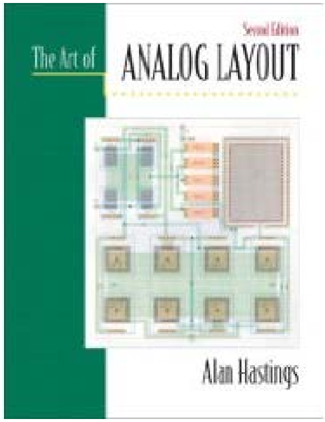
Reference Texts:

Fundamentals of Microelectronics
by B. Razavi, Wiley, 2013

CMOS Circuit Design, Layout, and Simulation (3rd Edition)
by Jacob Baker, Wiley-IEEE Press, 2010.

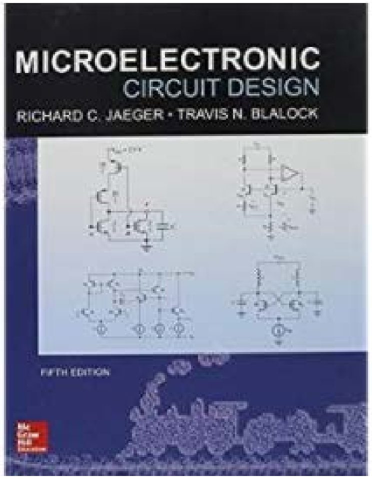


The Art of Analog Layout
by Alan Hastings, Prentice Hall, 2005

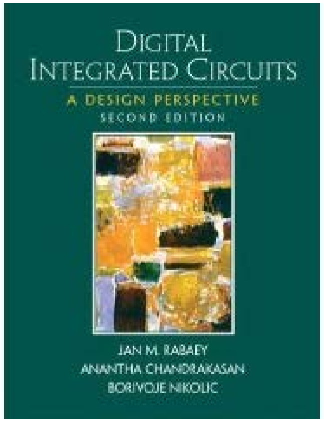


Reference Texts:

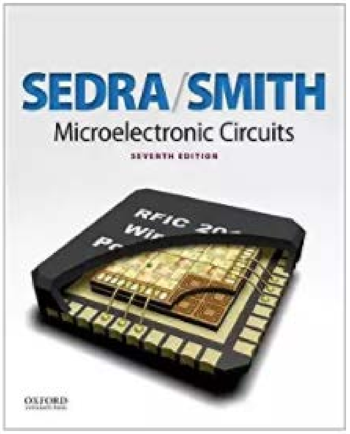
Microelectronic Circuit Design (4^{th} edition)
By Richard Jaeger and Travis Blalock,
McGraw Hill, 2015



Digital Integrated Circuits (2nd Edition)
by Jan M. Rabaey, Anantha Chandrakasan, Borivoje Nikolic, Pre
2003

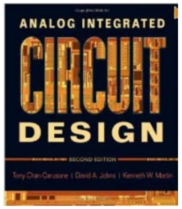


Microelectronic Circuits (7th Edition)
by Sedra and Smith, Oxford, 2014

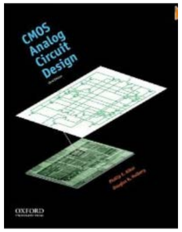


Other useful reference texts in the VLSI field:

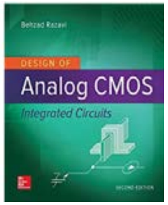
Analog Integrated Circuit Design (2nd edition)
by T. Carusone, D. Johns and K. Martin, Wiley, 2011



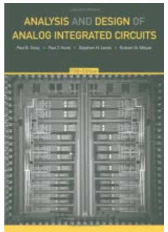
CMOS Analog Circuit Design (3rd edition)
by Allen and Holberg, Oxford, 2011.



Design of Analog CMOS Integrated Circuits
by B. Razavi, McGraw Hill, 2016



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



Untethered Communication Policy

Use them !

Hearing them ring represents business opportunity !

Please step outside of the room to carry on your conversations

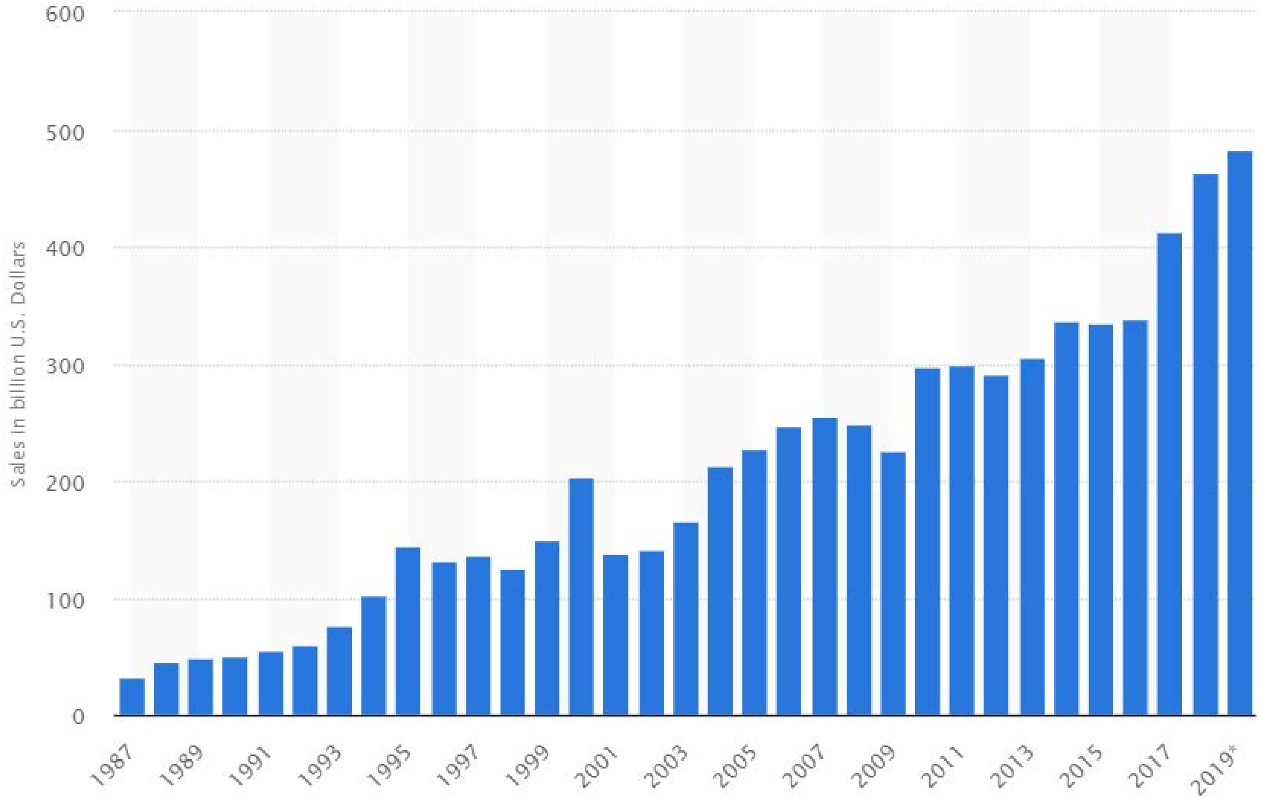
The Semiconductor Industry

(just the “chip” part of the business)

How big is it ?

How does it compare to other industries?

How big is the semiconductor industry?



Projected at $483 Billion in 2019

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

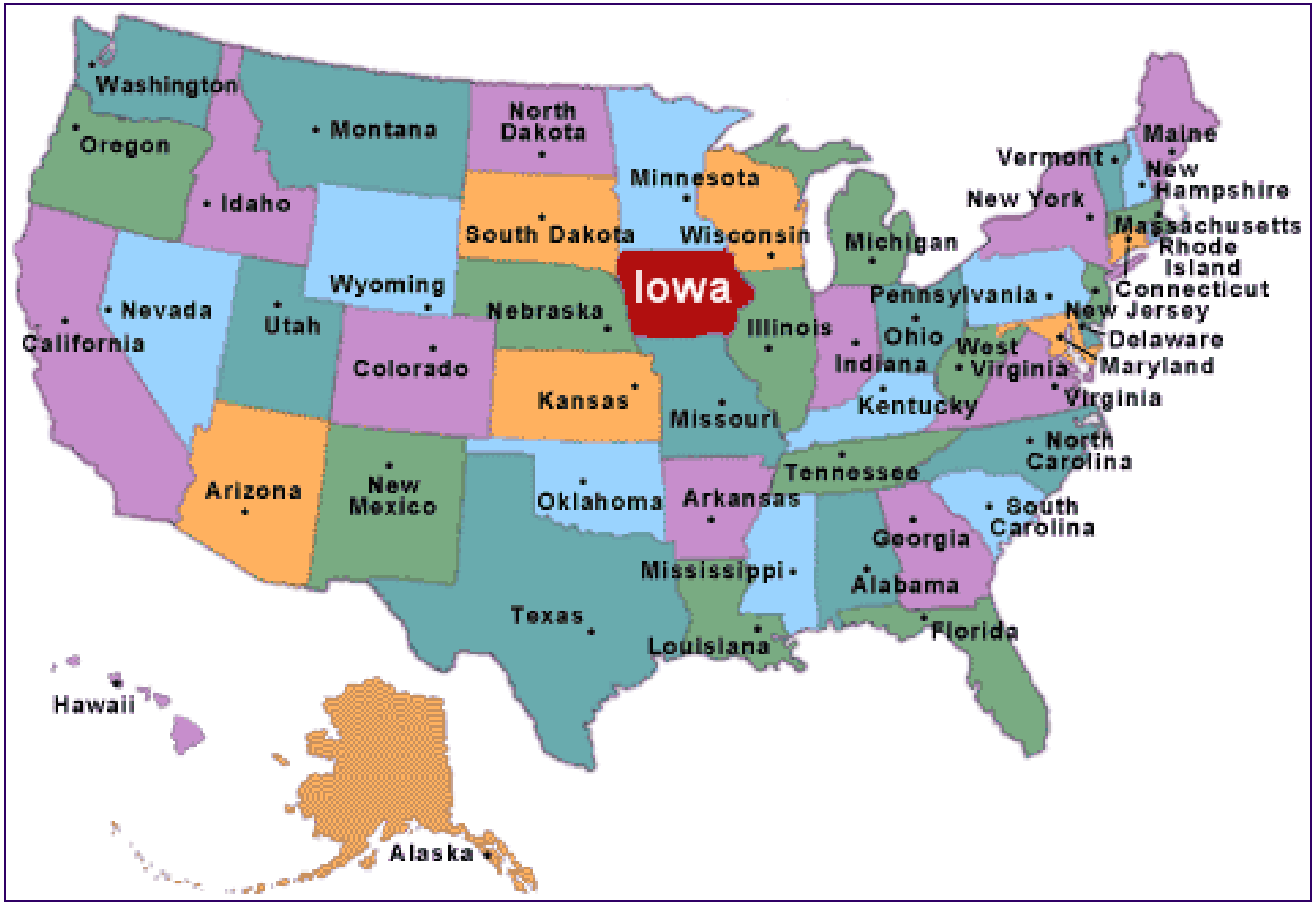
statista The Statistics Portal
Statistics and Studies from more than 22,500 Sources

The Semiconductor Industry

How big is it ?

How does it compare to Iowa-Centric Commodoties?

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

http://www.iowalifechanging.com/travel/iowafacts/statistics.html

Iowa-Centric Commodities

Corn

Beans

Iowa-Centric Commodities

Corn

Beans

Agricultural Commodities are a Major Part of the Iowa Economy

Value of Agricultural Commodities

Corn Production

	Bushels (Billions)
Iowa	**2.2**
United States	**12**
World	**23**

Soybean Production

	Bushels (Billions)
Iowa	**0.34**
United States	**3.1**
World	**8.0**

LANDUS COOPERATIVE

Not secure | www.landuscooperative.com/grain-bids/

Based upon Aug 17, 2018 closing markets in Boone Iowa

	Corn	Soybeans
Aug 2018	3.28	8.11

Value of Agricultural Commodities

(Based upon commodity prices in Boone Iowa on Aug 17 2018)

(simplifying assumption: value constant around world)

Corn Production

	Bushels (Billions)	Value (Billion Dollars)
Iowa	**2.2**	**$7.2**
United States	**12**	**$39**
World	**23**	**$75**

Soybean Production

	Bushels (Millions)	Value (Billion Dollars)
Iowa	**340**	**$2.8**
United States	**3,100**	**$25**
World	**8,000**	**$65**

Projected world 2019 semiconductor sales of $483B about 345% 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 $470B/Year and growing

How does it compare to Iowa-Centric Commodities?

Larger than major agricultural commodities (close to 3.5X)

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?

Worldwide Ranking of the Top-10 Suppliers of Semiconductors in 2017
(Ranking by Revenue in Millions of U.S. Dollars)

2016 Rank	2017 Rank	Company Name	2016 Revenue($)	2017 Revenue($)	Revenue Percent Change	Revenue Percent of Total	Revenue Cumulative Percent
2	1	Samsung Electronics	40,389	62,031	53.6%	14.5%	14.5%
1	2	Intel	54,980	61,406	11.7%	14.3%	28.8%
5	3	SK Hynix	14,699	26,638	81.2%	6.2%	35.0%
7	4	Micron Technology	12,710	22,843	79.7%	5.3%	40.3%
4	5	Broadcom Limited	14,979	17,375	16.0%	4.0%	44.3%
3	6	Qualcomm	15,405	16,872	9.5%	3.9%	48.3%
6	7	Texas Instruments	12,836	14,525	13.2%	3.4%	51.7%
8	8	Toshiba	9,904	11,864	19.8%	2.8%	54.4%
9	9	NXP	9,306	8,864	-4.7%	2.1%	56.5%
13	10	nVidia	6,030	8,578	42.3%	2.0%	58.5%
		Top 10 Companies	**191,238**	**250,996**	**31.2%**	**58.5%**	
		All Others	**161,356**	**178,112**	**10.4%**	**41.5%**	
		Total Semiconductor	**352,594**	**429,108**	**21.7%**	**100.0%**	

Source: IHS Markit Q1 2018 Competitive Landscaping Tool

1Q-2018 Top 15 Semiconductor Sales Leaders

May 15, 2018, anysilicon

Dramatic Dynamic Changes Ongoing

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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

How Do Engineers Working in the Semiconductor Industry Get Rewarded?

Solid State Devices

Signal Processing

Electronics

Power and Energy

Microelectronics

Communications

Control

2015 IEEE-USA Salary Survey: First, the Good News...

BY HELEN HORWITZ
Posted: 19 Oct 2015

2015 Major Results

Engineers in the general PATC of Communications Technology (Broadcast Technology, Communications, Consumer Electronics and Vehicular Technology) continue to enjoy the highest median earnings—$150,000, according to the 2015 Survey. The lowest median income in a broad PATC category is for those in Energy and Power Engineering—at $116,175. Other especially lucrative subspecialties include Information Theory, Solid-State Electronics, Lasers and Electro-Optics, and engineering management—all at median salaries of $150,000, or more, a year. The only subspecialties this year with median annual salaries less than $100,000 were Education and the Social Implications of Technology.

The differences are significant !!

e2af.com/trend/071210.shtml

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: 3840 x 2160 pixels (one UHD TV frame size)

Frame rate: 120 frames/second (one HDTV frame rate)

Pixel Resolution: 12 bits each RGB plus 12 bits alpha (48 bits/pixel) (no HDTV standard)

RAW (uncompressed) video data requirements: (3840*2160)*120*(48) = 48 G bits/sec
(some references show 36 G bits/sec)

8K UHD RAW (uncompressed) video data requirements: 144 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: 192K*24*2 = 9.2 Mbits/sec

- RAW video data rate approximately 5000X 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 UHD TV "movie" using RAW audio and video on a Verizon Smart Phone today?

Verizon Data Plan Jan 2016 (for over 12G per month) $3.5/GB

RAW (uncompressed) video data requirements = 48 G bits/sec

RAW (uncompressed) audio data requirements: 192K*24*2 = 9.2 Mbits/sec

Total bits: 48x60x120 Gb = 346,000 Gb

Total bytes: 48x60x120/8 GB = 43,000 GB

Total cost: $150,000

- 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 (UHDTV)

Video:

RAW (uncompressed) video data requirements: 48 G bits/sec

Audio:

RAW (uncompressed) audio data requirements: 192K*24*2 = 9.2 Mbits/sec

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

- UHDTV 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 Jan 2016 $3.50/GB

Total bytes: 43,000 GB/14 = 3070 GB

Total cost: $10,745

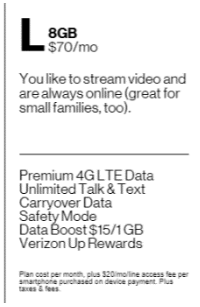
Moving audio and video data is still expensive and still challenging !

Data costs for cellular communications are dropping ?

(Verizon data plan of April 2014 is $15/GB from 1G to 3G increment)

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

(Verizon data plan of Aug 2018 is $15/GB over plan limit if not unlimited)



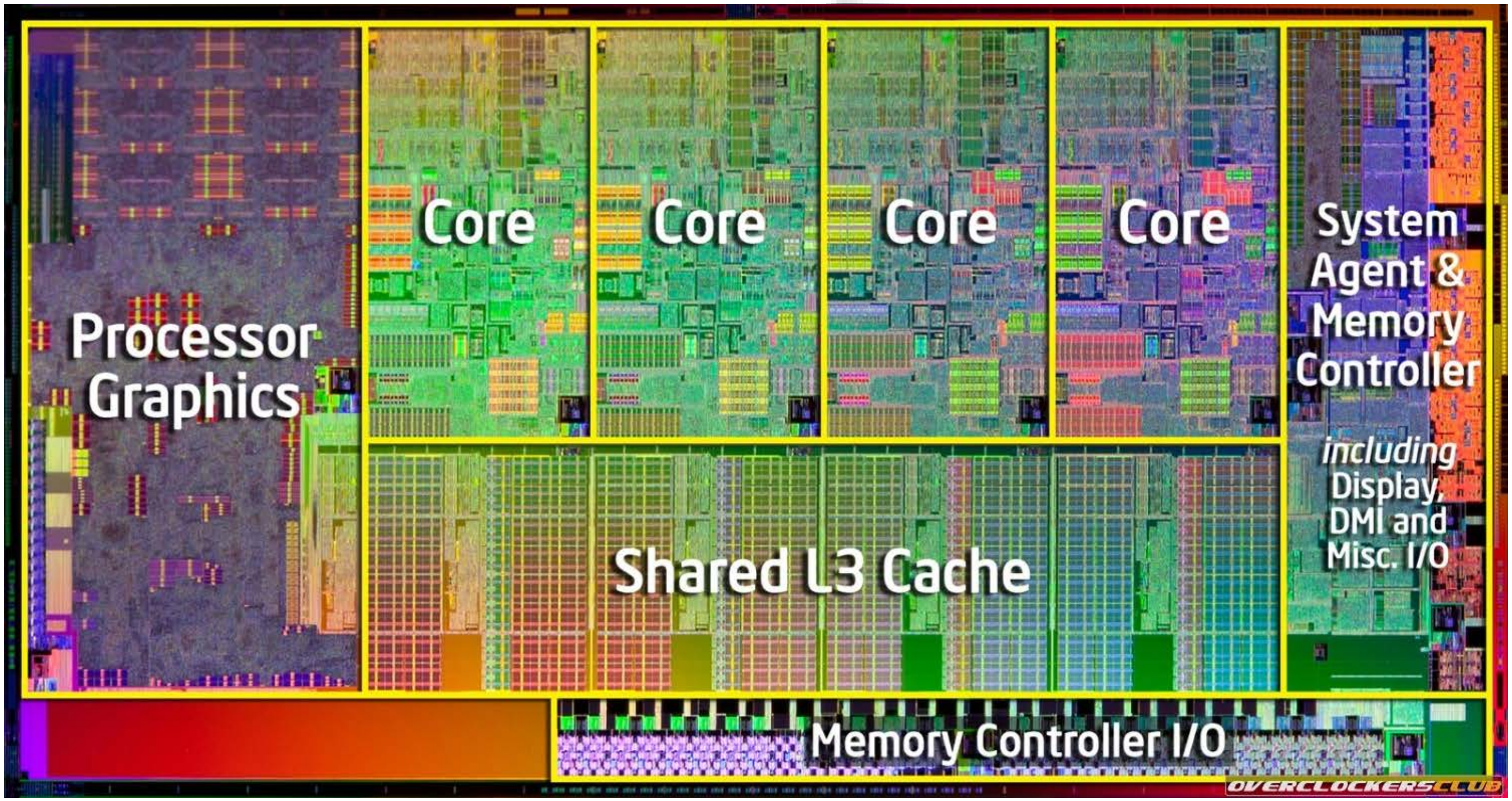
Challenge to Students

- 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

Recent Intel Processor

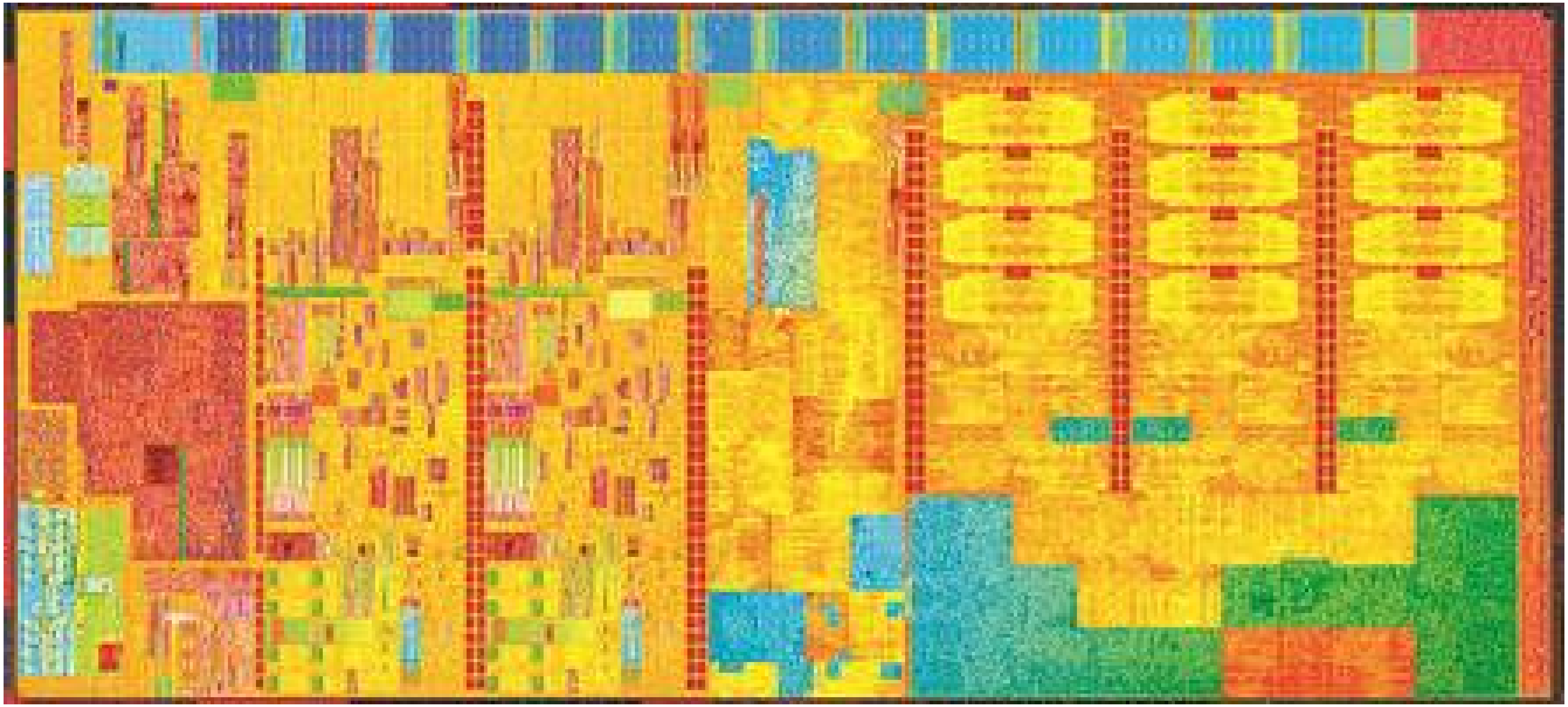


Processor

Quad-Core Intel® Core i7 Processor Up to 3.4GHz in 32nm CMOS

Power Dissipation: 95 watts

Today!



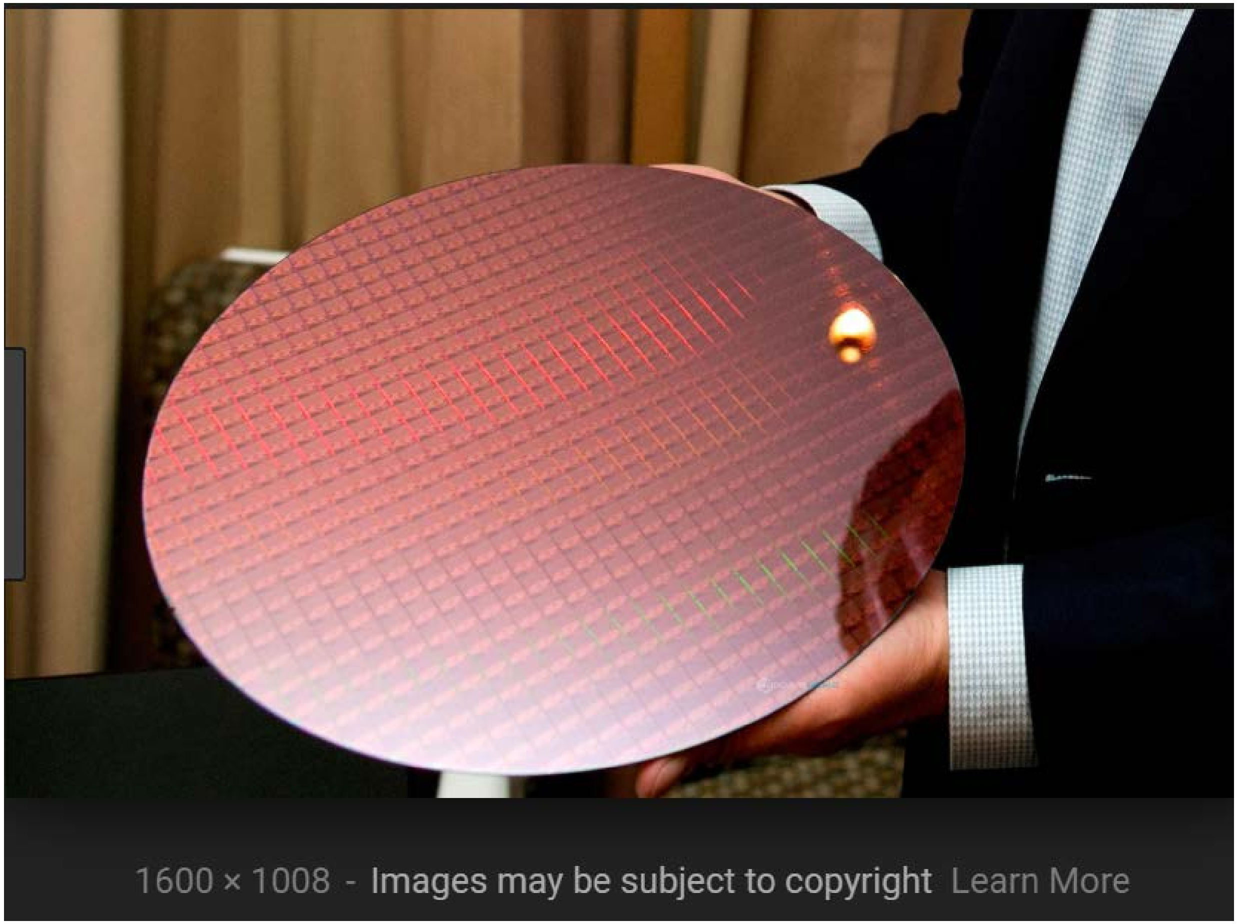
Processor

8-core (2.6B) 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

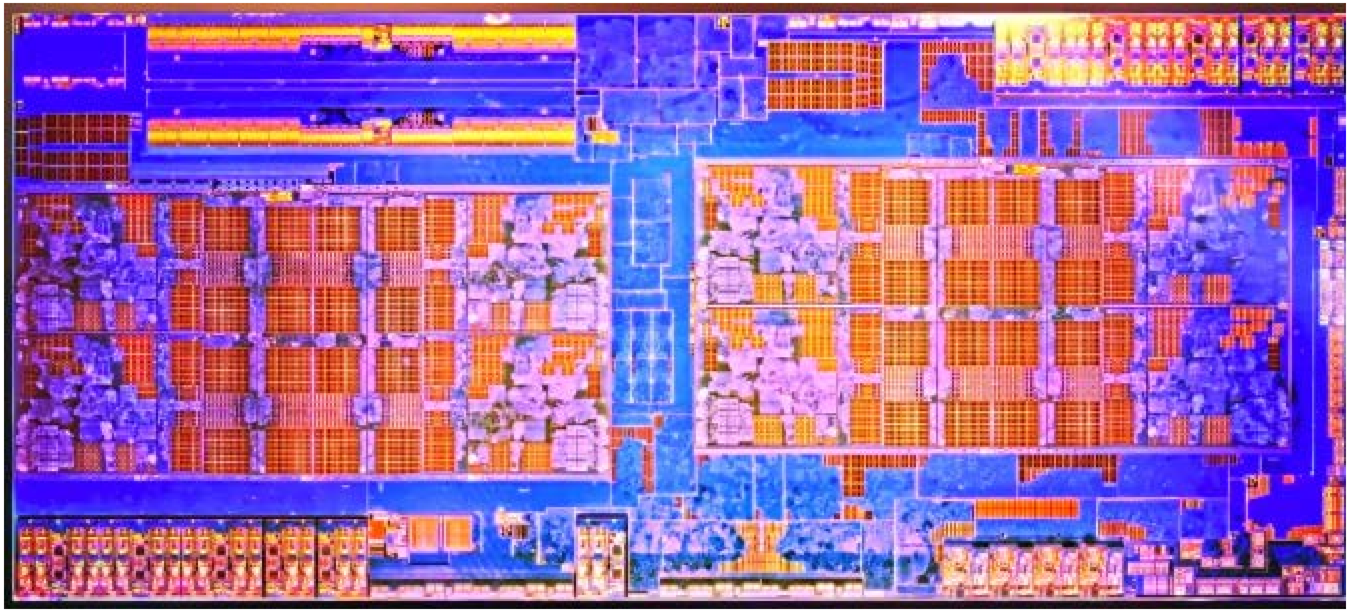
Today!



Cannon Lake Processor

10nm CMOS
i3-8121U
Delayed production schedule – expected to ramp up in 2019

Today!



AMD Zen 2

7nm CMOS

Sampling July 2018 – Volume production 2019

Today!

Microprocessors [edit]

See also: Microprocessor chronology

A microprocessor incorporates the functions of a computer's central processing unit on a single integrated circuit. It is a multipurpose, programmable device that accepts digital

Processor	Transistor count	Date of introduction	Designer	Process	Area
TMS 1000	8,000	1974[3]	Texas Instruments	8,000 nm	11 mm^2
Intel 4004	2,300	1971	Intel	10,000 nm	12 mm^2
Intel 8008	3,500	1972	Intel	10,000 nm	14 mm^2
MOS Technology 6502	3,510[4]	1975	MOS Technology	8,000 nm	21 mm^2
Motorola 6800	4,100	1974	Motorola	6,000 nm	16 mm^2
Intel 8080	4,500	1974	Intel	6,000 nm	20 mm^2
RCA 1802	5,000	1974	RCA	5,000 nm	27 mm^2
Intel 8085	6,500	1976	Intel	3,000 nm	20 mm^2
Zilog Z80	8,500	1976	Zilog	4,000 nm	18 mm^2
Motorola 6809	9,000	1978	Motorola	5,000 nm	21 mm^2
Intel 8086	29,000	1978	Intel	3,000 nm	33 mm^2
Intel 8088	29,000	1979	Intel	3,000 nm	33 mm^2
⋮					
Xbox One main SoC	5,000,000,000	2013	Microsoft/AMD	28 nm	363 mm^2
18-core Xeon Haswell-E5	5,560,000,000[39]	2014	Intel	22 nm	661 mm^2
IBM z14	6,100,000,000	2017	IBM	14 nm	696 mm^2
Xbox One X (Project Scorpio) main SoC	7,000,000,000[40]	2017	Microsoft/AMD	16 nm	360 mm^2[40]
IBM z13 Storage Controller	7,100,000,000	2015	IBM	22 nm	678 mm^2
22-core Xeon Broadwell-E5	7,200,000,000[41]	2016	Intel	14 nm	456 mm^2
POWER9	8,000,000,000	2017	IBM	14 nm	695 mm^2
72-core Xeon Phi	8,000,000,000	2016	Intel	14 nm	683 mm^2
IBM z14 Storage Controller	9,700,000,000	2017	IBM	14 nm	696 mm^2
32-core SPARC M7	10,000,000,000[42]	2015	Oracle	20 nm	
Centriq 2400	18,000,000,000[43]	2017	Qualcomm	10 nm	398 mm^2
32-core AMD Epyc	19,200,000,000	2017	AMD	14 nm	768 mm^2 (4 x 192 mm^2)

Today!

GPUs [edit]

A graphics processing unit (GPU) is a specialized electronic circuit designed to rapidly manipulate and alter memory to accelerate

Processor	Transistor count	Date of introduction	Manufacturer	Process	Area
NV3	3,500,000	1997	NVIDIA	350 nm	90 mm^2
Rage 128	8,000,000	1999	AMD	250 nm	70 mm^2
NV5	15,000,000	1999	Nvidia	250 nm	
NV10	23,000,000	1999	Nvidia	220 nm	111 mm^2
NV11	20,000,000	2000	Nvidia	180 nm	65 mm^2
NV15	25,000,000	2000	Nvidia	180 nm	81 mm^2

⋮

GP106 Pascal	4,400,000,000	2016	Nvidia	16 nm	200 mm^2
Tonga	5,000,000,000	2014	AMD	28 nm	366 mm^2
GM204 Maxwell	5,200,000,000	2014	Nvidia	28 nm	398 mm^2
Polaris 10 "Ellesmere"	5,700,000,000[51]	2016	AMD	14 nm	232 mm^2
Hawaii	6,300,000,000	2013	AMD	28 nm	438 mm^2
GK110 Kepler	7,080,000,000[52]	2012[53]	Nvidia	28 nm	561 mm^2
GP104 Pascal	7,200,000,000	2016	Nvidia	16 nm	314 mm^2
GM200 Maxwell	8,000,000,000	2015	Nvidia	28 nm	601 mm^2
Fiji	8,900,000,000	2015	AMD	28 nm	596 mm^2
GP102 Pascal	11,800,000,000	2016	Nvidia	16 nm	471 mm^2
Vega 10	12,500,000,000[54]	2017	AMD	14 nm	484 mm^2
GP100 Pascal	15,300,000,000[55]	2016	Nvidia	16 nm	610 mm^2
GV100 Volta	21,100,000,000[56]	2017	Nvidia	12 nm	815 mm^2

Today!

FPGA	Transistor count	Date of introduction	Manufacturer	Process	Area	Ref
Virtex	~70,000,000	1997	Xilinx			
Virtex-E	~200,000,000	1998	Xilinx			
Virtex-II	~350,000,000	2000	Xilinx	130 nm		
Virtex-II PRO	~430,000,000	2002	Xilinx			
Virtex-4	1,000,000,000	2004	Xilinx	90 nm		
Virtex-5	1,100,000,000	2006	Xilinx	65 nm		[57]
Stratix IV	2,500,000,000	2008	Altera	40 nm		[58]
Stratix V	3,800,000,000	2011	Altera	28 nm		[59]
Arria 10	5,300,000,000	2014	Altera	20 nm		[60]
Virtex-7	6,800,000,000	2011	Xilinx	28 nm		[61]
Stratix 10 Family device, 10GX5500/10SX5500	17,000,000,000	2017	Intel (formally Altera)	14 nm	560 mm^2	[62]
Virtex-Ultrascale XCVU440	20,000,000,000+	2014	Xilinx	20 nm		[63]
Everest	50,000,000,000	2018	Xilinx	7 nm		[64] [65]

Selected Semiconductor Trends

- Microprocessors
  - State of the art technology is now 10nm with over 20 Billion transistors on a chip
- DRAMS
  - State of the art is now 16G bits on a chip in a 10nm process which requires somewhere around 18 Billion transistors
- FPGA
  - FPGAs currently have over 50 Billion transistors with 7nm technology 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

End of Lecture 1