EE 330
Fall 2007

Integrated Electronics

Lecture Instructor: Randy Geiger
351 Durham
rlgeiger@iastate.edu 294-7745

Lab Instructors: Mike Beckman and Vaibhav Kumar

Lecture: MWF 12:10 1252 Howe

Lab:	Sec A	Tues	9:00 -10:50	1212 Coover
	Sec B	Wed	1:10 - 4:00	1212 Coover
	Sec C	Wed	4:10 – 7:00	1212 Coover
	Sec D	Thur	6:10 – 9:00	1212 Coover
	Sec E	Fri	1:10 – 4:00	1212 Coover

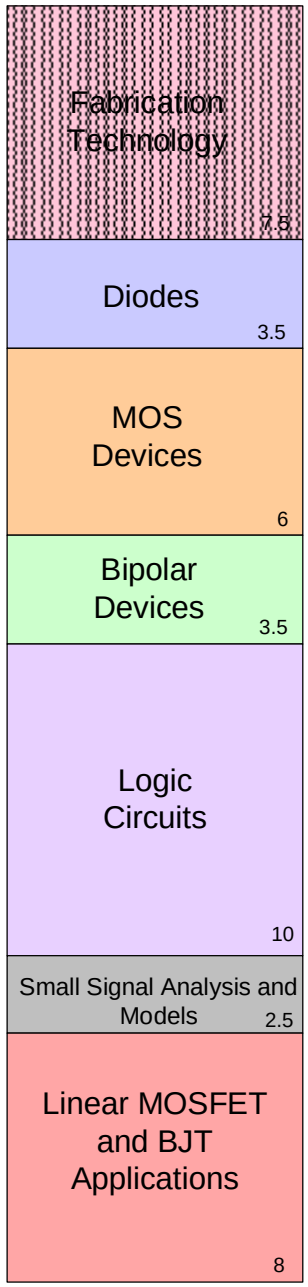
Catalog Description

E E 330. Integrated Electronics. (Same as Cpr E 330.) (3-3) Cr. 4. F.S. *Prereq:* 201, credit or enrollment in 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.

Topical Coverage

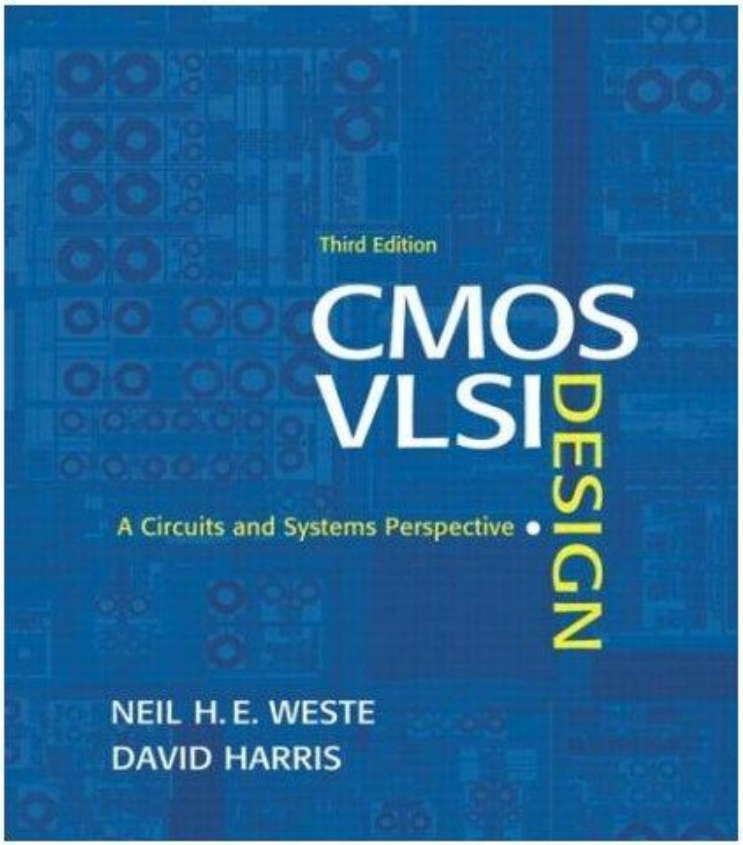
- Semiconductor Processes
- Device Models (Diode,MOSFET,BJT)
- Layout
- Simulation and Verification
- Basic Digital Building Blocks
- Behavioral Design and Synthesis
  - Standard cells
- Basic Analog Building Blocks

Topical Coverage Weighting



Textbook:

CMOS VLSI Design – A Circuits and Systems Perspective
by Weste and Harris Addison Wesley/Pearson, 2005



Grading Policy

2 Exams	100 pts each
1 Final	100 pts.
Homework	100 pts.total
Quizzes	15 pts each
Lab and Lab Reports	100 pts.total
Design Project (tentative)	100 pts.

If for any reason the final examination is waived, the two listed examinations will be weighted 150 points each.

Instructor Access:

- Office Hours
  - Open-door policy
  - MWF 1:00-2:00
    - reserved for EE 330 and EE 508 students
  - By appointment
- Email
  - rlgeiger@iastate.edu
  - Include **EE 330** in subject

Teaching Assistant Access:

Mike Beckman

– beckmann@iastate.edu

– Room 1313 Coover Cube 15

Viabhav Kumar

-viabhav@iastate.edu

- Room 310 Durham

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

Reference Texts:

Microelectronic Circuits (5th Edition)
by Sedra and Smith, Oxford, 2004

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

Analog Integrated Circuit Design
by D. Johns and K. Martin, Wiley, 1997

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

CMOS Circuit Design, Layout, and Simulation (2nd Edition)
by Jacob Baker, Wiley-IEEE Press, 2004.

VLSI Design Techniques for Analog and Digital Circuits
by Geiger, Allen and Strader, McGraw Hill, 1990

CMOS Analog Circuit Design
by Allen and Holberg, HRW, 2002.

Other 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-Fourth Edition
Gray,Hurst, Lewis and Meyer, Wiley, 2001

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

Digital Integrated Circuit Design
by Ken Martin, Oxford, 1999.

Cell Phone Policy




Use them !

Hearing them ring represents business opportunity !

Please step outside of the room to carry on your conversations

The Semiconductor Industry

How big is it ?

How does it compare to other industries?

How big is the semiconductor industry?

From : http://www.gartner.com/teleconferences/asset_144017_75.jsp

Gartner

SEARCH RESEARCH

Advanced Browse Help

Why Use Gartner | Products & Services | Analysts & Consultants | About Gartner | Gartner Websites

Pre-recorded Teleconference

→ See Upcoming Teleconferences

1st Quarter 2006 Semiconductor Forecast Update

15 February 2006

The semiconductor market grew by about 7 percent to a record $235 billion in 2005. Further growth is expected in 2006, which should take the market to a new high above the $250 billion mark. However, strong double digit growth in 2006 is not expected as the industry continues to invest cautiously in incremental capacity additions to meet modest demand growth. The medium term forecast calls for a cyclical market peak in 2008. Longer term, a cyclical downturn is forecast for 2009 before the beginning of the next industry cycle in 2010. As the New Year gets underway, Gartner's revised semiconductor forecast is presented giving an update on supply side fundamentals, device market trends and application drivers.

LISTEN TO REPLAY

MP3 (70 minutes)

Teleconference Hosts

Bob Johnson
Research VP

How big is the semiconductor industry?

1984	$25B
1990	$50B
1994	$100B
2004	$200B
2006	$250B (est)

At the current growth rate, it will top $300B before the end of this decade!

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

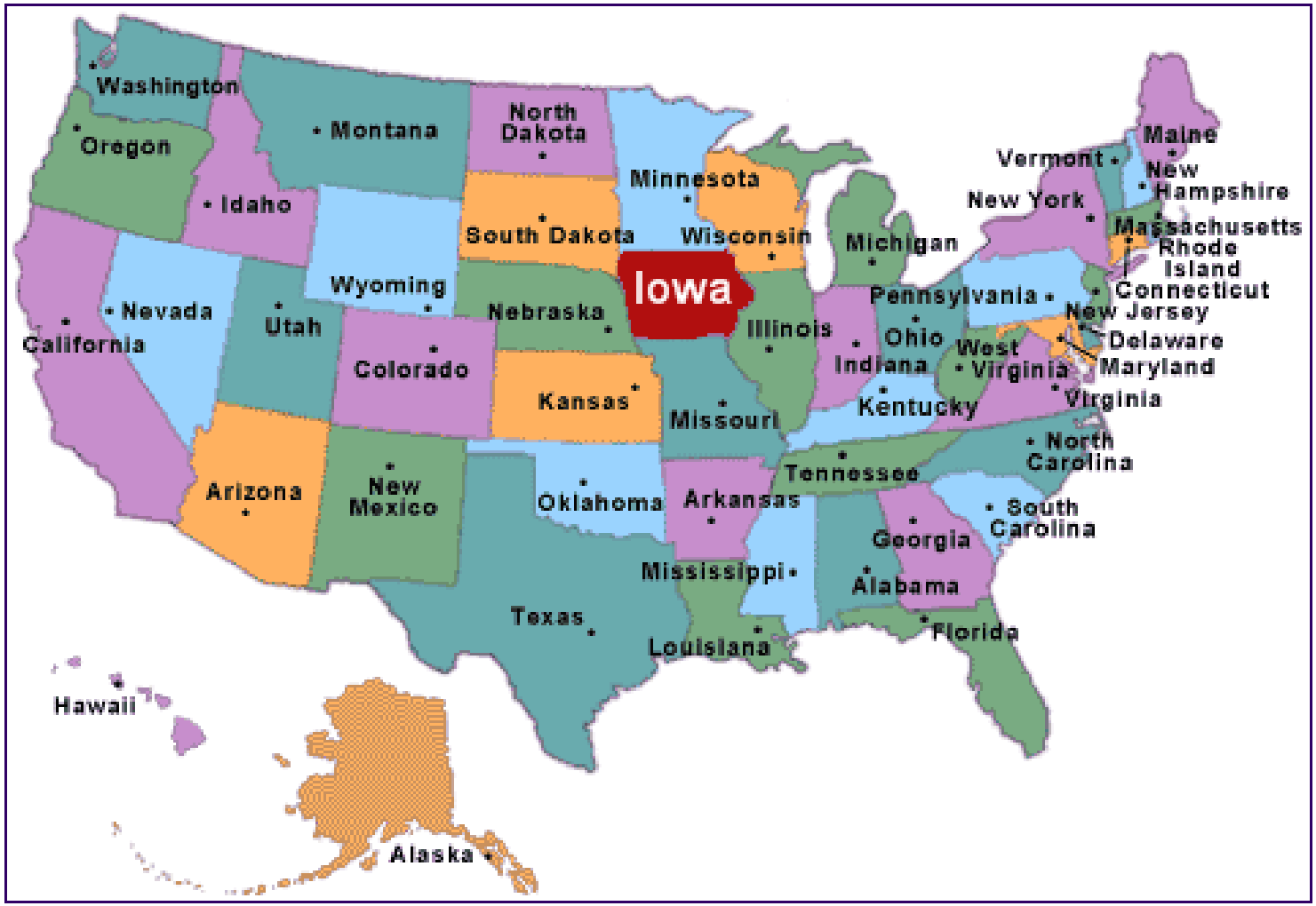
The Semiconductor Industry

How big is it ?

How does it compare to other industries?

- **Relative to Iowa-Centric Commodities**
- **Relative to Oil Production**

Iowa-Centric Commodities



Iowa-Centric Commodities

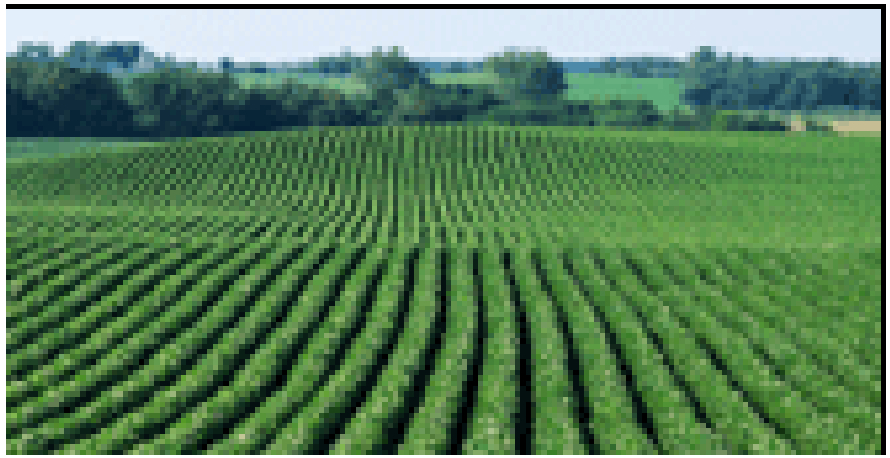
In the United States, Iowa ranks:

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

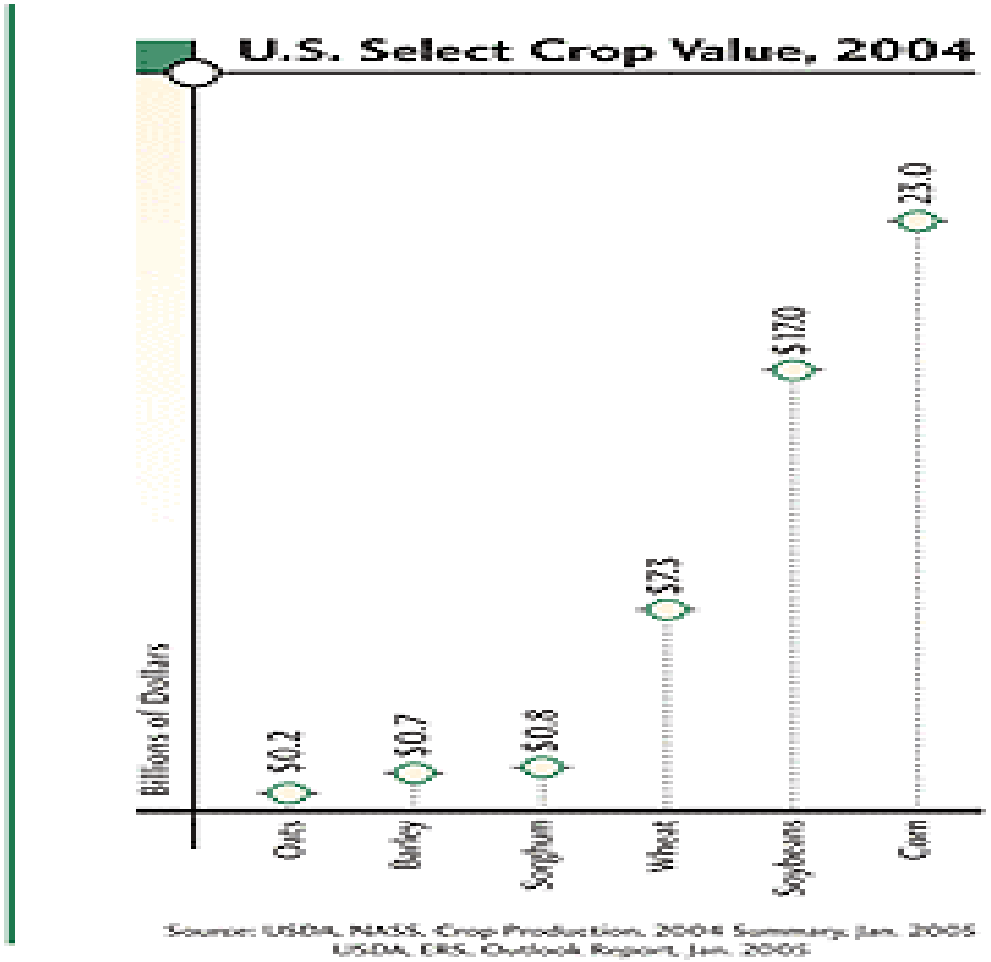
Iowa-Centric Commodities

Corn

Beans

Agricultural Commodities are a Major Part of the Iowa Economy

Value of Agricultural Commodoties



Corn and Beans Dominate the US Agricultural Comodoties

Value of Agricultural Commodities

Corn Production

	Bushels (Billions)
Iowa	**2.24**
United States	**11.8**
World	**23.3**

Soybean Production

	Bushels (Millions)
Iowa	**338**
United States	**3,141**
World	**7,968**

From: http://www.west-central2.com/grainbids/grainbidslive.asp

Updated: 08/21/2006 10:22:15

Cash Corn Bids

DELIVERY PERIOD	AUG 2006	SEPT 2006	O/N 2006	DEC 2006	JAN 2007	MAR 2007	JULY 2007
BOONE	1.78 0.00	1.78 0.00	1.81 0.00	1.88 0.00	2.03 0.01	2.08 0.01	2.24 0.01

Cash Soybean Bids

DELIVERY PERIOD	AUG 2006	SEPT 2006	O/N 2006	DEC 2006	JAN 2007	MAR 2007	JULY 2007
BOONE	4.89 0.01	4.96 0.01	5.03 0.01	5.16 0.00	5.23 0.00	5.35 0.00	5.52 0.00

From: http://www.west-central2.com/grainbids/grainbidslive.asp

Updated: 01/08/2007 09:51:45

Cash Corn Bids

DELIVERY PERIOD	JAN 2007	FEB 2007	MAR 2007	MAY 2007	JULY 2007	O/N 2007	JAN08 2008
BOONE	3.26 -0.03	3.29 -0.03	3.31 -0.03	3.39 -0.04	3.47 -0.03	3.18 -0.02	3.24 -0.03

Cash Soybean Bids

DELIVERY PERIOD	JAN 2007	FEB 2007	MAR 2007	MAY 2007	JULY 2007	O/N 2007	JAN08 2008
BOONE	6.15 -0.03	6.23 -0.03	6.29 -0.03	6.41 -0.02	6.53 -0.02	6.76 -0.02	6.83 -0.02

Value of Agricultural Commodities

(Based upon commodity prices for most of the past decade)

Corn Production

	Bushels (Billions)	Value (Billion Dollars)
Iowa	**2.24**	**$3.98**
United States	**11.8**	**$21.0**
World	**23.3**	**$41.5**

Soybean Production

	Bushels (Millions)	Value (Billion Dollars)
Iowa	**338**	**$1.65**
United States	**3,141**	**$15.4**
World	**7,968**	**$39.0**

World 2005 semiconductor sales of $235B approx a factor of 3 larger than total corn and soybean production!

Value of Agricultural Commodities

(Based upon commodity prices as of today)

Corn Production

	Bushels (Billions)	Value (Billion Dollars)
Iowa	**2.24**	**$7.3**
United States	**11.8**	**$38.5**
World	**23.3**	**$76.0**

Soybean Production

	Bushels (Millions)	Value (Billion Dollars)
Iowa	**338**	**$2.08**
United States	**3,141**	**$19.3**
World	**7,968**	**$49.0**

World 2006 semiconductor sales of $250B approx a factor of 2 larger than total corn and soybean production!

The Semiconductor Industry

How big is it ?

How does it compare to other industries?

- **Relative to Iowa-Centric Commodities**
- **Relative to Oil Production**

Value of Oil

	Barrels/Day (Million)
United States	20
Western Europe	15
Japan	5.6
China	5.5
Russia	2.7
World	80

Value of Oil

	Barrels/Year (Billion)	Value (Billion Dollars)	Value (Billion Dollars)
		(@$20/barrel)	(@$50/barrel)
United States	**7.3**	**$146**	**$365**
Western Europe	**5.5**	**$110**	**$275**
Japan	**2.0**	**$40**	**$100**
China	**2.0**	**$40**	**$100**
Russia	**0.99**	**$19.8**	**$49.5**
World	**29.2**	**$584**	**$1460**

World 2005 semiconductor sales of $235B a factor of 2.5 to 7 smaller than total oil production!

Electronic system sales much larger than semiconductor sales !!

The Semiconductor Industry

How big is it ?

About $250B/Year and growing rapidly

How does it compare to other industries?

- **Relative to Iowa-Centric Commodities**

  Much larger than major agricultural commodities

Relative to Oil Production

Factor of 2 to 4 smaller than energy

The semiconductor industry is one of the largest sectors in the world economy and is rapidly growing

How is the semiconductor industry distributed around the world?

2004 Worldwide Top 50 Semiconductor Sales Leaders - 6/16/2005 - Pur... http://www.purchasing.com/article/CA609239.html

2004 Worldwide Top 50 Semiconductor Sales Leaders

By James Carbone

Purchasing June 16, 2005

2004 Worldwide Top 50 Semiconductor Sales Leaders

2004 Rank	2003 Rank	Company	Headquarters	2003 ($M)	2004 ($M)	04/03 % change
1	1	Intel	U.S.	27,030	30,900	14%
2	2	Samsung	South Korea	10,400	15,830	52%
3	3	TI	U.S.	8,250	10,700	30%
4	7	Infineon	Europe	7,109	9,180	29%
5	4	Renesas	Japan	7,970	9,000	13%
6	6	ST	Europe	7,238	8,760	21%
7	5	Toshiba	Japan	7,355	8,531	16%
8	8	TSMC*	Taiwan	5,855	7,648	31%
9	9	NEC	Japan	5,603	6,469	15%
10	11	Philips	Europe	4,512	5,692	26%
11	10	Freescale	U.S.	4,654	5,519	19%
12	13	Sony	Japan	3,933	5,070	29%

13	12	AMD/Spansion	U.S.	3,940	5,001	27%
14	15	Micron	U.S.	3,575	4,652	30%
15	20	Hynix	South Korea	2,516	4,648	85%
16	14	Matsushita	Japan	3,675	4,265	16%
17	19	UMC*	Taiwan	2,740	3,900	42%
18	18	Fujitsu	Japan	2,955	3,440	16%
19	17	Sharp	Japan	3,035	3,355	11%
20	22	Qualcomm**	U.S.	2,466	3,224	31%
21	16	IBM	U.S.	3,115	3,150	1%
22	21	Rohm	Japan	2,490	2,818	13%
23	24	Analog Devices	U.S.	2,100	2,570	22%
24	28	Broadcom**	U.S.	1,610	2,401	49%
25	23	Sanyo	Japan	2,245	2,150	-4%
26	29	National	U.S.	1,560	2,048	31%
27	27	Agilent	U.S.	1,635	2,011	23%
28	26	Nvidia**	U.S.	1,820	1,975	9%
29	25	Agere	U.S.	1,920	1,807	-6%
30	38	ATI**	Canada	1,135	1,725	52%

31	30	Oki	Japan	1,360	1,720	26%
32	56	Powerchip	Taiwan	666	1,716	158%
33	50	Elpida	Japan	760	1,700	124%
34	35	Maxim	U.S.	1,229	1,662	35%
35	31	Atmel	U.S.	1,331	1,653	24%
36	42	Sandisk**	U.S.	982	1,603	63%
37	32	Xilinx**	U.S.	1,304	1,585	22%
38	33	Fairchild	U.S.	1,273	1,458	15%
39	37	Seiko Epson	Japan	1,150	1,325	15%
40	52	ProMOS	Taiwan	729	1,283	76%
41	40	ON Semi	U.S.	1,065	1,263	19%
42	34	LSI Logic	U.S.	1,270	1,248	-2%
43	48	Nanya	Taiwan	825	1,211	47%
44	36	Mitsubishi	Japan	1,155	1,210	5%
45	49	Marvell**	U.S.	780	1,190	53%
46	41	IR	U.S.	1,050	1,185	13%
47	39	MediaTek**	Taiwan	1,104	1,172	6%
48	53	Chartered*	Singapore	728	1,103	52%
49	45	MagnaChip***	South Korea	831	1,085	31%
50	47	Altera**	U.S.	827	1,016	23%
		Top 10 Total		**91,322**	**112,710**	**23%**
		Top 25 Total		**136,371**	**168,873**	**24%**
		Top 50 Total		**164,860**	**205,827**	**25%**

**Foundry*
***Fabless*
****Includes total from Hynix in '03 & '04*

Selected Semiconductor Trends

- Microprocessors
- DRAMS
- FPGA

• Press Room Home
Press Releases
Press Resources
Corporate Information
Press Room Site Index
Contact Intel PR

Search Press Room

Microprocessor Quick Reference Guide

print

Learn all the significant processor evolution facts, including introduction date, ratings and number of transistors. Click on the processor family below to view facts on each processor in that family, or scroll down the page to see them all. For a fun and informative overview of Intel processor history, visit the interactive History of the Microprocessor.

Intel® Pentium® M Processor

Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Bus Speed	Core Voltage	Thermal Design Power (TDP)	Typical Use
Intel® Pentium® M Processor 770 760 750 740 730	2.13 GHz 2 GHz 1.86 GHz 1.73 GHz 1.60 GHz	Jan. 19, 2005 770 760 750 740 730	90 nm 140 million	2 MB L2 cache	533 MHz	1.260-1.3 72 V Max Perf. Mode 0.988V Battery Optimized Mode	27 W	Full-size and thin & light mobile PCs
Intel® Pentium® M Processor 765 755 745 735 725 715	2.10 GHz 2 GHz 1.80 GHz 1.70 GHz 1.60 GHz 1.50 GHz	Oct. 20, 2004 765 June 23, 2004 725 715 May 10, 2004 755 745 735	90 nm 140 million	2 MB L2 cache	400 MHz	1.276-1.340V Max Perf. Mode 0.988V Battery Optimized Mode	21 W	Full-size and thin & light mobile PCs
Intel® Pentium® M Processor	1.70 GHz 1.60 GHz 1.50 GHz 1.40 GHz 1.30 GHz	June 2, 2003 1.70 GHz Mar. 12, 2003 1.60 GHz 1.50 GHz 1.40 GHz 1.30 GHz	0.13-micron 77 million	1 MB L2 cache	400 MHz	1.484V in Max. Perf. Mode 0.956V Battery Optimized Mode (1.40-1.70 GHz) 1.39V in Max Perf. Mode 0.96V in Battery Optimized Mode (1.30 GHz)	24.5 W	Full-size and thin & light mobile PCs

Intel® Itanium® Processor Family

Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Typical Use
Intel® Itanium® 2 Processor	1.60 GHz	Nov.8, 2004	0.13 micron 592 million	9 MB L3 Cache	Demanding enterprise-class servers and high-performance applications
Intel® Itanium® 2 Processor	1.60 GHz	Nov.8, 2004	0.13 micron 592 million	6 MB L3 Cache	Demanding enterprise-class servers and high-performance applications
Intel® Itanium® 2 Processor	1.50 GHz	Nov.8, 2004	0.13 micron 592 million	4 MB L3 Cache	Demanding enterprise-class servers and high-performance applications
Intel® Itanium® 2 Processor	1.60 GHz	Nov.8, 2004	0.13 micron 592 million	3 MB L3 Cache	For dual processor servers
Intel® Itanium® 2 Processor	1.60 GHz 1.40 GHz	April 14, 2004	0.13-micron 410 million	3 MB L3 Cache	Technical computing clusters and entry-level, front-end enterprise systems
Intel® Itanium® 2 Processor (for dual processor systems)	1.40 GHz	Sept. 8, 2003	0.13-micron 410 million	1.5 MB L3 Cache	Dual processor servers
Intel® Itanium® 2 Processor	1.50 GHz	June 30, 2003	0.13-micron 410 million	6 MB L3 Cache	Demanding enterprise-class servers, and high-performance applications
Intel® Itanium® 2 Processor	1 GHz 900 MHz	July 8, 2002	0.18-micron 220 million	3 MB and 1.5 MB L3 Cache	Demanding enterprise-class servers, and high-performance applications
Intel® Itanium® Processor	800 MHz 733 MHz	May 2001	0.18-micron 25 million	2 MB and 4 MB L3 Cache	Demanding enterprise-class servers, and high-performance applications

Intel® Pentium® 4 Processor

Desktop

Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Bus Speed	Typical Use
Intel® Pentium® 4 Processor Extreme Edition supporting HT Technology	3.73 GHz	Feb. 21, 2005	90nm 169 million	2 MB L2 cache	1066 MHz	Gaming and Computing Enthusiasts
Intel® Pentium® 4 Processor Extreme Edition supporting HT Technology	3.46 GHz	Nov. 15, 2004	0.13-micron 178 million	2 MB L3 cache; 512 KB L2 cache	1066 MHz	Gaming and Computing Enthusiasts
Intel® Pentium® 4 Processor Extreme Edition supporting HT Technology	3.40 GHz 3.20 GHz	June 21, 2004 3.40 GHz (Intel® LGA775 package technology) Feb. 2, 2004 3.40 GHz Nov. 3, 2003 3.20 GHz	0.13-micron 178 million	2 MB L3 cache; 512 KB L2 cache	800 MHz	Gaming and Computing Enthusiasts
Intel® Pentium® 4 Processor supporting HT Technology 660 650 640 630	3.60 GHz 3.40 GHz 3.20 GHz 3 GHz	Feb. 21, 2005 660 650 640 630	90nm 169 million	2 MB L2 cache	800 MHz	Desktops and entry-level workstations
Intel® Pentium® 4 Processor supporting HT Technology 570 560 550 540 530 520	3.80 GHz 3.60 GHz 3.40 GHz 3.20 GHz 3 GHz 2.80 GHz	Nov. 15, 2004 570 June 21, 2004 560 550 540 530 520	90nm 125 million	1 MB L2 cache	800 MHz	Desktops and entry-level workstations

Intel® Pentium® 4 Processor supporting HT Technology	3.40 GHz 3.20E GHz 3E GHz 2.80E GHz	Feb. 2, 2004	90nm 125 million	1 MB L2 cache	800 MHz	Desktops and entry-level workstations
Intel® Pentium® 4 Processor supporting HT Technology	3.40 GHz 3.20 GHz 2.80C GHz 2.60C GHz 2.40C GHz	Feb. 2, 2004 3.40 GHz June 23, 2003 3.20 GHz May 21, 2003 2.80 GHz 2.60 GHz 2.40 GHz	0.13-micron 55 million	512 KB Advanced Transfer L2 cache	800 MHz	Desktops and entry-level workstations
Intel® Pentium® 4 Processor supporting HT Technology	3 GHz	Apr. 14, 2003	0.13-micron 55 million	512 KB Advanced Transfer L2 cache	800 MHz	Desktops and entry-level workstations
Intel® Pentium® 4 Processor supporting HT Technology	3.06 GHz	Nov. 14, 2002	0.13-micron 55 million	512 KB Advanced Transfer L2 cache	533 MHz	Desktops and entry-level workstations
Intel® Pentium® 4 Processor	2.80 GHz 2.66 GHz 2.53 GHz 2.40 GHz 2.26 GHz	Aug. 26, 2002 2.80 GHz 2.66 GHz May 6, 2002 2.53 GHz 2.40 GHz 2.26 GHz	0.13-micron 55 million	512 KB Advanced Transfer L2 cache	533 MHz	Desktops and entry-level workstations
Intel® Pentium® 4 Processor	2.60 GHz 2.50 GHz 2.40 GHz 2.20 GHz 2 GHz	Aug. 26, 2002 2.60 GHz 2.50 GHz Apr. 2, 2002 2.40 GHz Jan. 7, 2002 2.2 GHz Aug. 27, 2001 2 GHz	0.13-micron 55 million	512 KB Advanced Transfer L2 cache	400 MHz	Desktops and entry-level workstations
Intel® Pentium® 4 Processor	2 GHz 1.90 GHz 1.80 GHz 1.70 GHz 1.60 GHz 1.50 GHz 1.40 GHz	Aug. 27, 2001 2 GHz 1.90 GHz Jul. 2, 2001 1.80 GHz 1.60 GHz Apr. 23, 2001 1.70 GHz Nov. 20, 2000 1.50 GHz 1.40 GHz	0.18-micron 42 million	256 KB Advanced Transfer L2 cache	400 MHz	Desktops and entry-level workstations

Intel® Celeron® Processor

Desktop

Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Bus Speed	Typical Use
Intel® Celeron® D Processor 345 340 335 330 325 320	3.06 GHz 2.93 GHz 2.80 GHz 2.66 GHz 2.53 GHz 2.40 GHz 2.26 GHz	Nov. 23, 2004 345 Sep. 22, 2004 340 June 24, 2004 335 330 325 320	90 nm	256 KB L2 cache	533 MHz	Value and Mobile PCs
Intel® Celeron® Processor	2.80 GHz 2.70 GHz	Nov. 5, 2003 2.80 GHz Sept. 24, 2003 2.70 GHz	0.13-micron	128 KB L2 cache	400 MHz	Value and Mobile PCs
Intel® Celeron® Processor	2.40 GHz 2.30 GHz 2.20 GHz 2.10 GHz	Mar. 31, 2003 2.40 GHz 2.30 GHz Nov. 20, 2002 2.20 GHz 2.10 GHz	0.13-micron	128 KB L2 cache	400 MHz	Value PCs
Intel® Celeron® Processor	2 GHz	Sept. 18, 2002	0.13-micron	128 KB L2 cache	400 MHz	Value PCs
Intel® Celeron® Processor	1.80 GHz 1.70 GHz	June 12, 2002 1.80 GHz May 15, 2002 1.70 GHz	0.18-micron	128 KB L2 cache	400 MHz	Value PCs
Intel® Celeron® Processor	1.40 GHz 1.30 GHz 1.20 GHz	May 15, 2002 1.40 GHz Jan. 3, 2002 1.30 GHz Oct. 2, 2001 1.20 GHz	0.13-micron	256 KB L2 cache	100 MHz	Value PCs

Intel® Celeron® Processor	1.10 GHz 1 GHz 950 MHz 990 MHz 850 MHz 800 MHz	Aug. 31, 2001 1.10 GHz 1 GHz 950 MHz Jul. 2, 2001 900 MHz May 21, 2001 850 MHz Jan. 3, 2001 800 MHz	0.18-micron	128 KB L2 cache	100 MHz	Value PCs
Intel® Celeron® Processor	766 MHz 733 MHz 700 MHz 667 MHz 633 MHz 600 MHz 566 MHz	Nov. 13, 2000 766 MHz 733 MHz June 26, 2000 700 MHz 667 MHz 633 MHz March 29, 2000 600 MHz 566 MHz	0.18-micron	128 KB L2 cache	66 MHz	Value PCs
Intel® Celeron® Processor	533 MHz 500 MHz 466 MHz 433 MHz 400 MHz 366 MHz 333 MHz 300 MHz	Jan. 4, 2000 533 MHz Aug. 2, 1999 500 MHz Apr. 26, 1999 466 MHz Mar. 22, 1999 433 MHz Jan. 4, 1999 400 MHz 366 MHz Aug. 24, 1998 333 MHz Aug. 24, 1998 300A MHz	0.25-micron 19 million	128 KB L2 cache	66 MHz	Value PCs
Intel® Celeron® Processor	300 MHz 266 MHz	June 8, 1998 300 MHz Apr. 15, 1998 266 MHz	0.25-micron 7.5 million	NA	66 MHz	Value PCs

Intel® Pentium® III Processor

Desktop						
Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Bus Speed	Typical Use
Intel® Pentium® III Processor	1 GHz 933 MHz 866 MHz 850 MHz	Mar. 8, 2000 1 GHz Mar. 20, 2000 866 MHz 850 MHz May 24, 2000 933 MHz	0.18-micron 28 million	256 KB Advanced Transfer cache	100 MHz 133 MHz	Business, consumer PCs; 1- and 2-way servers and workstations
Intel® Pentium® III Processor	733 MHz 700 MHz 667 MHz 650 MHz 600 MHz 550 MHz 533 MHz 500 MHz	Oct. 25, 1999	0.18-micron 28 million	256 KB Advanced Transfer cache	100 MHz 133 MHz	Business, consumer PCs; 1- and 2-way servers and workstations
Intel® Pentium® III Processor	600 MHz 550 MHz 500 MHz 450 MHz	Aug. 2, 1999 600 MHz May 17, 1999 550 MHz	0.25-micron 9.5 million	512 KB	100 MHz	Business, consumer PCs; 1- and 2-way servers and workstations
		Feb. 26, 1999 500 MHz 450 Mhz				

Intel® Pentium® III Xeon™ Processor

Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Addressable Memory	Bus Speed	Typical Use
Intel® Pentium® III Xeon™ Processor	900 MHz	Mar. 21, 2001	0.18-micron 28 million	2 MB Advanced Transfer L2 cache	64 GB	100 MHz	High-end servers, 4- and 8-way multiprocessing systems
Intel® Pentium® III Xeon™ Processor	933 MHz	May 24, 2000	0.18-micron 28 million	256 KB Advanced Transfer L2 cache	64 GB	133 MHz	Business and consumer PCs, 1- and 2-way servers and workstations
Intel® Pentium® III Xeon™ Processor	700 MHz	May 22, 2000	0.18-micron 28 million	1 MB and 2 MB Advanced Transfer L2 cache	64 GB	100 MHz	4- and 8-way servers
Intel® Pentium® III Xeon™ Processor	866 MHz 800 MHz 733 MHz 667 MHz 600 MHz	Apr. 10, 2000 866 MHz Jan. 12, 2000 800 MHz Oct. 25, 1999 733 MHz 667 MHz 600 MHz	0.18-micron 28 million	256 KB Advanced Transfer L2 cache	64 GB	133 MHz	2-way servers and workstations
Intel® Pentium® III Xeon™ Processor	550 MHz 500 MHz	Mar. 17, 1999	0.25-micron 9.5 million	512 KB, 1 MB and 2 MB Advanced Transfer L2 cache	64 GB	100 MHz	Business PCs, 2-, 4- and 8-way (and higher) servers and workstations

Intel® Pentium® II Xeon™ Processor

Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Addressable Memory	Bus Speed	Typical Use
Intel® Pentium® II Xeon™ Processor	450 MHz	Jan. 5, 1999	0.25-micron 7.5 million	512 KB 1 MB 2 MB	64 GB	100 MHz	4-way servers and workstations
Intel® Pentium® II Xeon™ Processor	450 MHz	Oct. 6, 1998	0.25-micron 7.5 million	512 KB	64 GB	100 MHz	Dual-processor servers and workstations
Intel® Pentium® II Xeon™ Processor	400 MHz	June 29, 1998	0.25-micron 7.5 million	512 KB 1 MB	64 GB	100 MHz	Midrange and higher servers and workstations

Intel® Pentium® II Processor

Desktop						
Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Cache	Bus Speed	Typical Use
Intel® Pentium® II Processor	450 MHz	Aug. 24, 1998	0.25-micron 7.5 million	512 KB	100 MHz	Business and consumer PCs; 1- and 2-way servers and workstations.
Intel® Pentium® II Processor	400 MHz 350 MHz	Apr. 15, 1998	0.25-micron 7.5 million	512 KB	100 MHz	Business and consumer PCs; 1- and 2-way servers and workstations.
Intel® Pentium® II Processor	333 MHz	Jan. 26, 1998	0.25-micron 7.5 million	512 KB	66 MHz	Business and consumer PCs; 1- and 2-way servers and workstations.
Intel® Pentium® II Processor	300 MHz 266 MHz 233 MHz	May 7, 1997	0.35-micron 7.5 million	512 KB		High-end business desktops, workstations and servers.

Intel® Pentium® Processor Family

Desktop				
Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Typical Use
Intel® Pentium® Processor with MMX™ Technology	233 MHz	June 2, 1997	0.35-micron 4.5 million	High-performance desktops and servers
Intel® Pentium® Processor with MMX™ Technology	200 MHz 166 MHz	Oct. xx, 1996	0.35-micron 4.5 million	High-performance desktops and servers
Intel® Pentium® Processor	200 MHz	June 10, 1996	0.35-micron 3.3 million	High-performance desktops and servers
Intel® Pentium® Processor	166 MHz 150 MHz	Jan. 4, 1996	0.35-micron 3.3 million	High-performance desktops and servers
Intel® Pentium® Processor	133 MHz	June 1995	0.35-micron 3.3 million	High-performance desktops and servers
Intel® Pentium® Processor	120 MHz	Mar. 27, 1995	0.6-micron 0.35-micron 3.3 million	Desktops and notebooks
Intel® Pentium® Processor	100 MHz 90 MHz	Mar. 7, 1994	0.6-micron 3.3 million	Desktops
Intel® Pentium® Processor	75 MHz	Oct. 10, 1994	0.6-micron 3.3 million	Desktops and notebooks
Intel® Pentium® Processor	66 MHz 60 MHz	Mar. 22, 1993	0.8-micron 3.1 million	Desktops

Intel486™ Processors and Earlier

Processor	Clock Speed(s)	Intro Date(s)	Mfg. Process/ Transistors	Transistors	Addressable Memory	Typical Use
Intel486™ SL Processor	33 MHz 25 MHz 20 MHz	Nov. 9, 1992	0.8-micron	1.4 million	64 MB	First CPU specifically designed for Notebook PCs
IntelDX4™ Processor	100 MHz 75 MHz	Mar. 7, 1994	0.6-micron	1.6 million	4 GB	High-performance, entry-level desktops and value notebooks
IntelDX2™ Processor	66 MHz 50 MHz 40 MHz	Aug. 10, 1992 66 Mhz Mar. 3, 1992 50 Mhz June 1993 40MHz	0.8-micron	1.2 million	4 GB	High-performance, low-cost desktops
Intel486™ SX Processor	33 MHz 25 MHz 20 MHz 16 MHz	Sept. 21, 1992 33 MHz Sept. 16, 1991 25 MHz 20 MHz 16 MHz	0.8 -micron 33 MHz 25 MHz 20 MHz 16 MHz	0.8-micron 900,000 1-micron 1.2 million	4 GB	Low-cost, entry-level desktops
Intel386™ SL Processor	25 MHz 20 MHz	September 30, 1991 25 MHz Oct. 15, 1990 20 MHz	1-micron	855,000	4 GB	First CPU designed specifically for portables
Intel486™ DX Processor	50 MHz 33 MHz 25 MHz	June 24, 1991 50 MHz May 7, 1990 33 MHz Apr. 10, 1989 25 MHz	0.8-micron 50 MHz 1-micron 33 MHz 25 MHz	1.2 million	4 GB	Desktops and servers.
Intel386™ SX Processor	33 MHz 25 MHz 20 MHz 16 MHz	Oct. 26, 1992 33 MHz 25 MHz Jan. 25, 1989 20 MHz June 16, 1988 16 MHz	1.5- micron	275,000	16 MB	Entry-level desktop and portable computing
Intel386™ DX Processor	33 MHz 25 MHz 20 MHz 16 MHz	Apr. 10, 1989 33 MHz Apr. 4, 1988 25 MHz Feb. 16, 1987 20 MHz Oct. 17, 1985 16 MHz	1-micron 33 MHz 1.5 micron 25 MHz 20 MHz 16 MHz	275,000	4 GB	Desktops

80286	12 MHz 10 MHz 6 MHz	February 1982	1.5-micron	134,000	16 MB	Desktops (standard CPU for all IBM PCs clones at the time)
80186	12 MHz 10 MHz	1982				Used mostly in controller applications
8088	8 MHz 5 MHz	June 1979	3-micron	29,000		Desktops (standard CPU for all IBM PCs and PC clones at the time)
8086	10 MHz 8 MHz 5 MHz	June 8, 1978	3-micron	29,000	1 MB	Portable computing
8085	2 MHz	March 1976	3-micron	6,500	64 KB	Toledo scale. Computed cost from weight and price. High level of integration, operating for first time on a single 5-volt power supply (down from 12 volts).
8080	2 MHz	April 1974	6-micron	6,000	64 KB	Traffic light controller, Altair computer (first PC).
8008	200 KHz	April 1972	10-micron	3,500	16 KB	Dumb terminals, general calculators, bottling machines, data/character manipulation
4004	108 KHz	Nov. 1971	10-micron	2,300	640 Bytes	Busicom calculator, arithmetic manipulation

IBM pc 1981

Apple IIe 1977

IBM PC (model 5150)
Type Personal computer
Released August 12, 1981
Discontinued April 2, 1987
Processor Intel 8088 @ 4.77 MHz
3u NMOS technology
Memory16KB ~ 640KB
OS IBM BASIC / PC-DOS 1.0

Processor 6502 @ 1 MHz
Memory 4 KB to 48KB
1975 – Probably 5u NMOS technology

Selected Semiconductor Trends

- Microprocessors
  - State of the art technology is now 65nm with over 1Billion transistors on a chip
- DRAMS
  - State of the art is now 2G bits on a chip which requires somewhere around 2.5 Billion transistors
- FPGA
  - FPGAs currently have over 800Million transistors and are growing larger

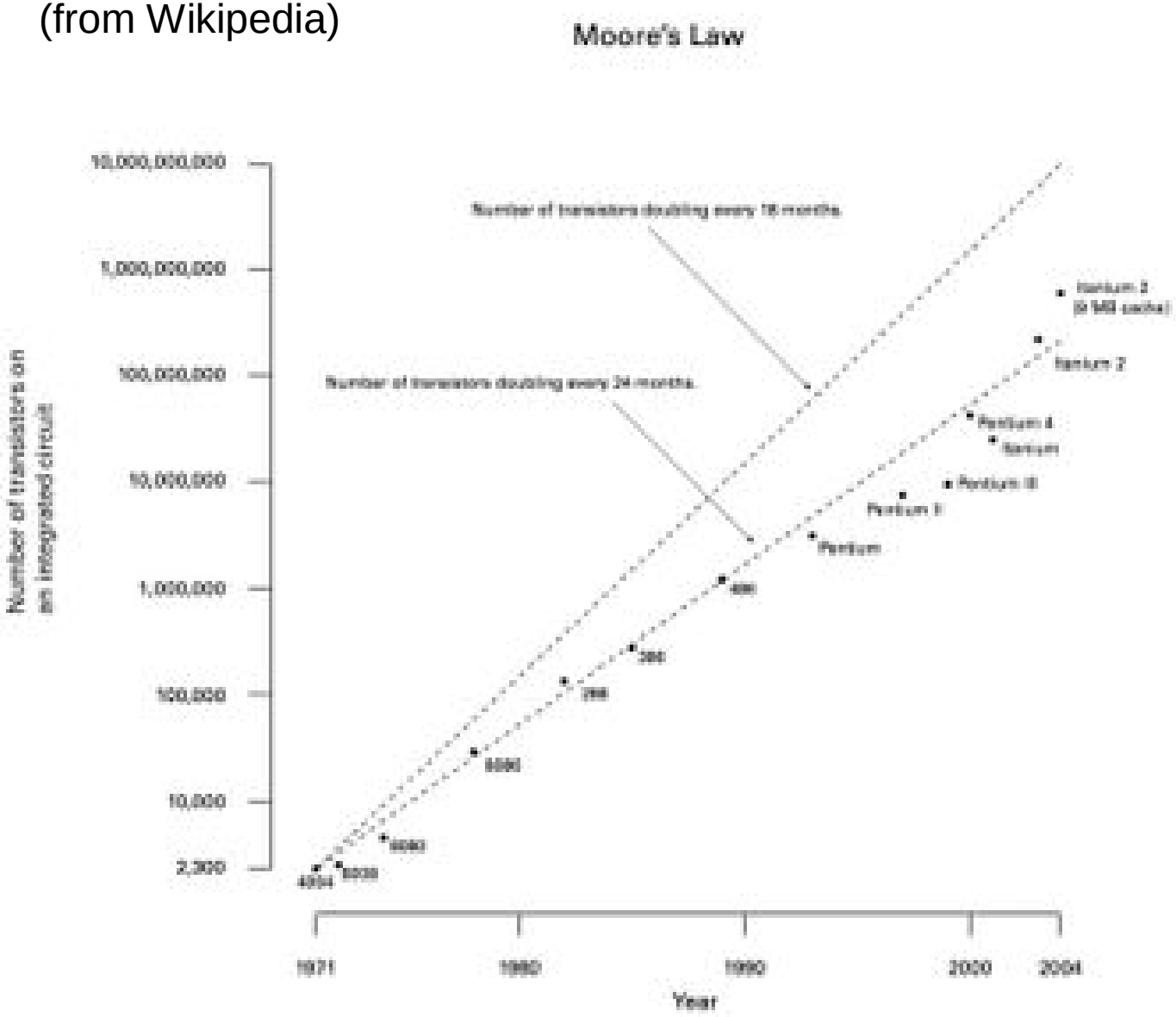
Device count on a chip has been increasing rapidly with time, device size has been decreasing rapidly with time and speed/performance has been rapidly increasing

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.

(from Wikipedia)

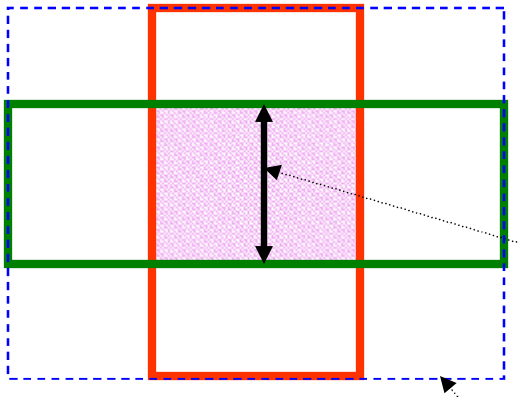


Growth of transistor counts for Intel processors (dots) and Moore's Law (upper line=18 months; lower line=24 months)

Year	Processor name	Transistor count	Mininum feature size
1971	4004	2300	10 micron
1972	8008	3500	10 micron
1974	8080	6000	6 micron
1976	8085	6500	3 micron
1978	8086	29000	3 micron
1982	80286	134,000	1.5 micron
1985	80386	275,000	1.5 micron
1989	Intel486	1.2 million	1 micron
1993	Pentium	3.1 million	800 nanometer
1997	Pentium II	7.5 million	350 nanometer
1999 (Feb.)	Pentium III	9.5 million	250 nanometer
1999 (Oct.)	Pentium III	28 million	180 nanometer
Source: Intel			

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



Feature Size of
MOS Transistor

Bounding Region

Bounding region often a factor of 10 or more larger
Than area of transistor itself

Moore's Law

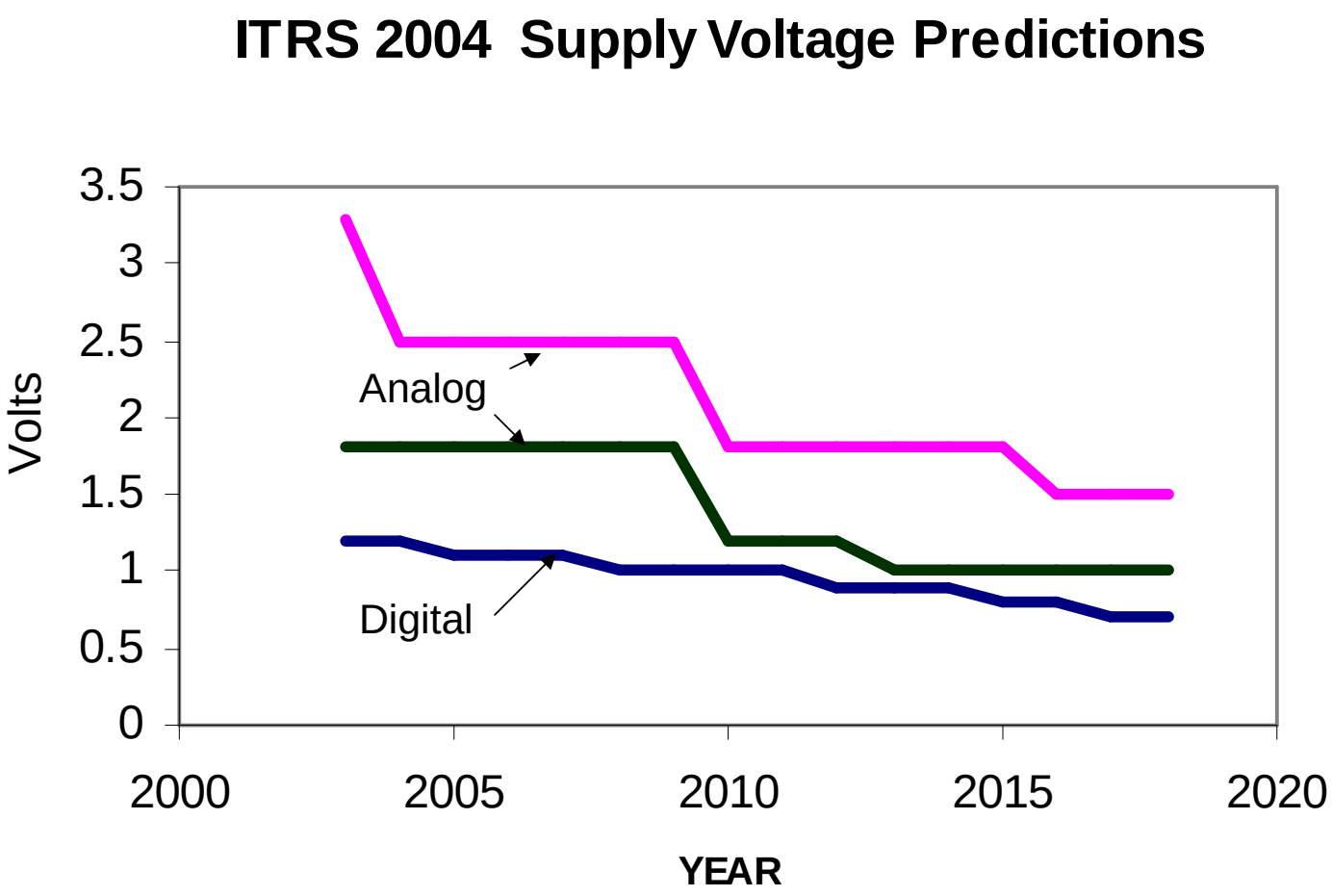
(from Wikipedia)

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.

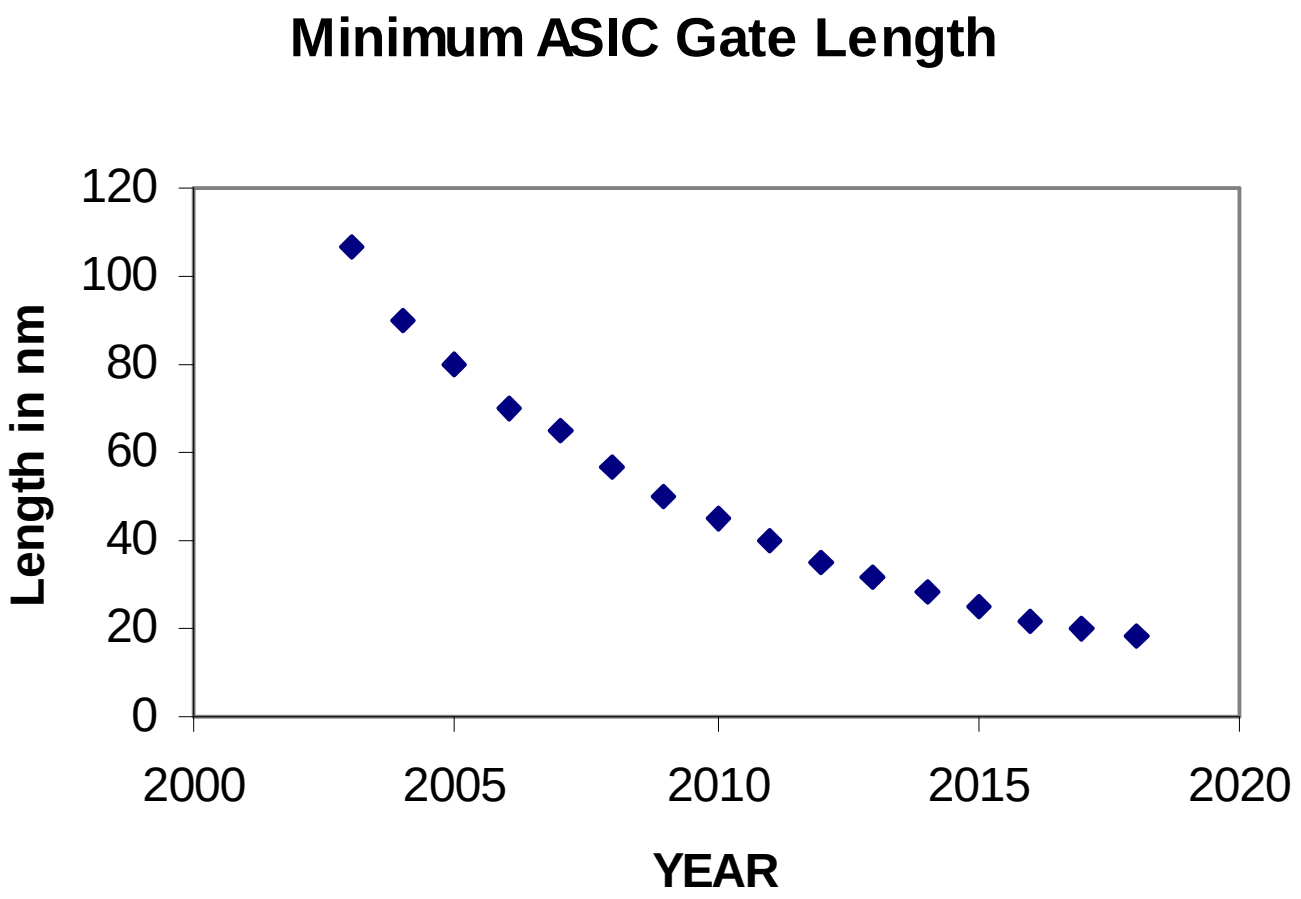
- Often misinterpreted or generalized
- Many say it has been dead for several years
- Many say it will continue for a long while
- Not intended to be a long-term prophecy about trends in the semiconductor field

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

ITRS Technology Predictions



ITRS Technology Predictions



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