EE 330
Fall 2021

Integrated Electronics

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

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

Lecture: MWF 12:05 –12:55

Lab:				
	Sec 1	Tues	8:00 - 10:50	TA:
	Sec 2	Tues	11:00 - 1:50	TA:
	Sec 3	Wed	5:30 - 8:20	TA:
	Sec 4	Fri	7:45 - 10:35	TA:
	Sec 5	Thur	8:00 - 10:50	TA:

Labs start this week !
HW Assignment 1 will be posted later today and is due this Friday

As a courtesy to fellow classmates, TAs, and the instructor

Wearing of masks during lectures and in the laboratories for this course would be appreciated irrespective of vaccination status

Laboratory Instructors and TAs:

1. Douglas Zuercher	dougz@iastate.edu
2. Margaret Heaslip	mheaslip@iastate.edu
3. Julio Torres	jgtorres@iastate.edu
4. Nick Moser	nsmoser@iastate.edu

Instructor Access:

- Office Hours
  - To Be Announced
  - By appointment at other times
- Email
  - rlgeiger@iastate.edu
  - Include **EE 330** in subject

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

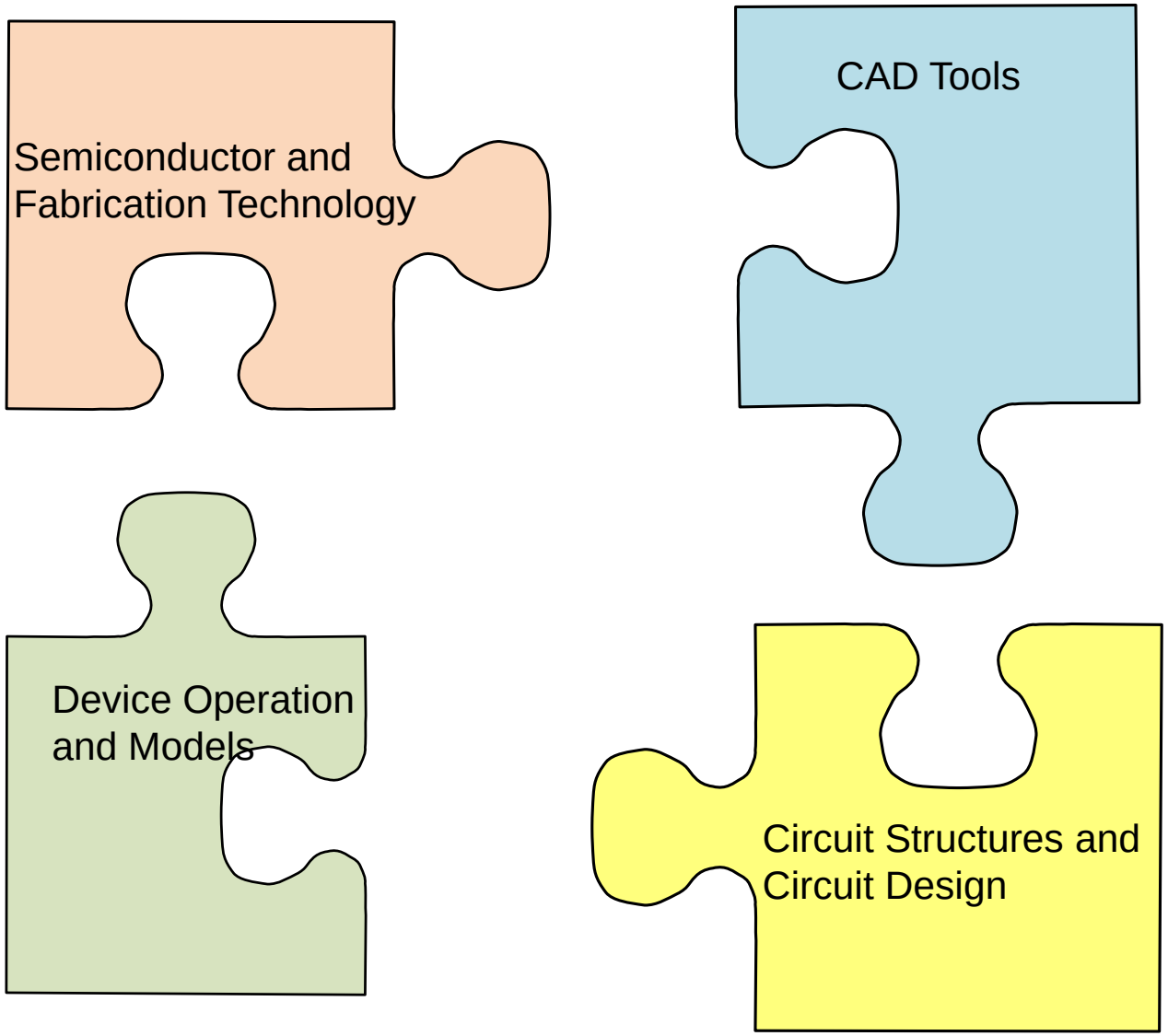
- Almost all electronic circuits are, at the most fundamental level, an interconnection of transistors and some passive components such as resistors, capacitors, and inductors

- 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

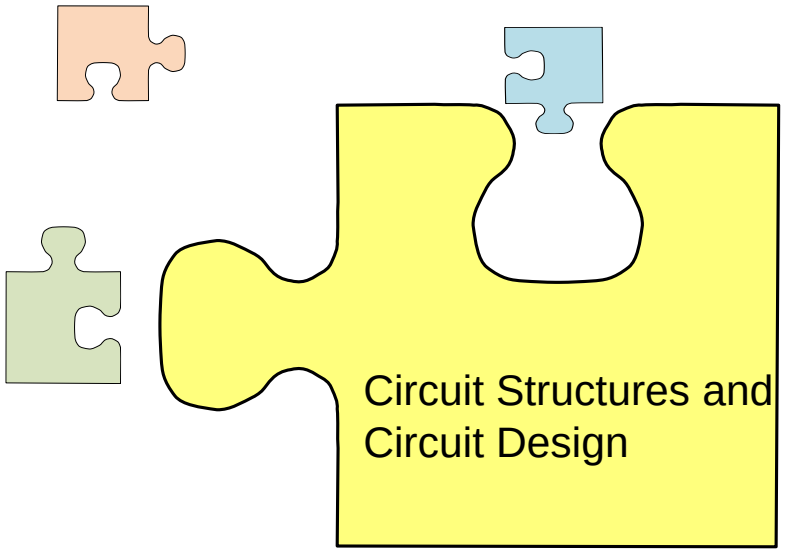
- A basic understanding of semiconductor and fabrication technology and device modeling is necessary to use transistors in the design of useful integrated circuits

How Integrated Electronics will be Approached



Will initially bounce back and forth between these topics – but have faith !

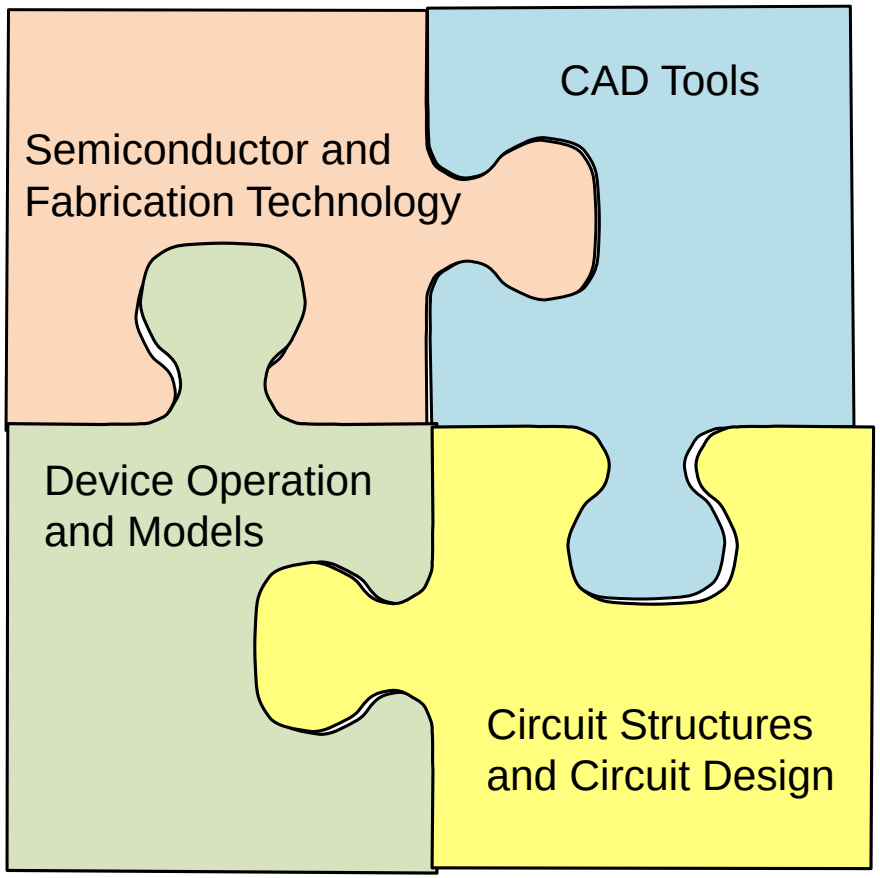
How Electronics was Approached for Decades



Coupling of electronic circuits with fabrication technology was weak and device models were simple

How Integrated Electronics will be Approached

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



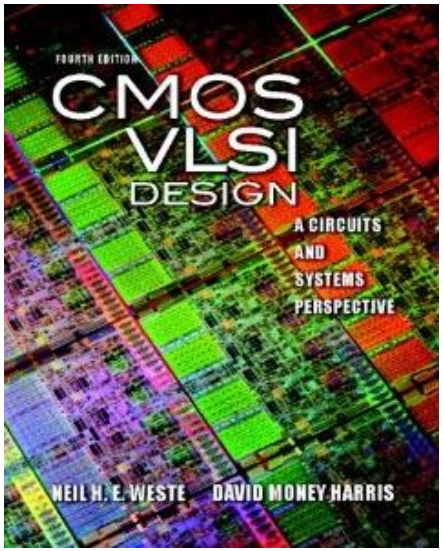
The sequencing of laboratory experiments has been intentionally structured so that on some topics, a laboratory investigation will lead a topic in the classroom and in others it will follow

Topical Coverage

- Semiconductor Processes
- Device Models (Diode,MOSFET,BJT, Thyristor)
- Layout
- Simulation and Verification (using commercial state of the art toolsets)
- Basic Digital Building Blocks
- Behavioral Design and Synthesis
  - Standard cells
- Basic Analog Building Blocks

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	100 pts each
1 Final	100 pts.
Homework	100 pts.total
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

Studying for this course:

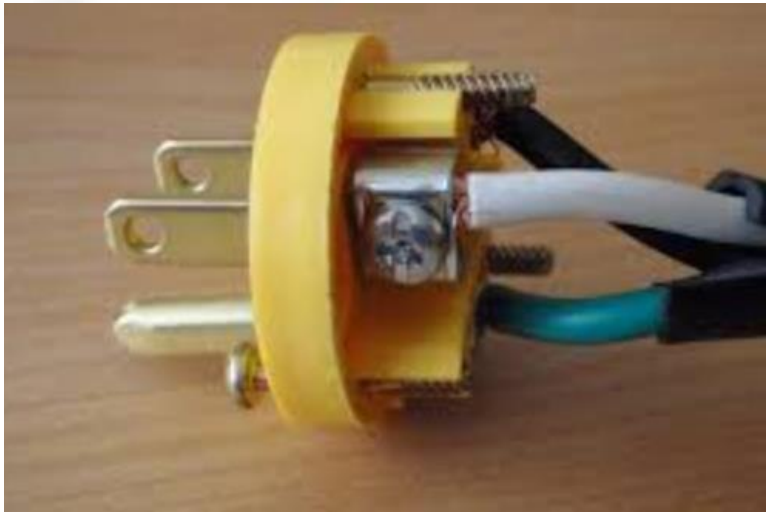
- By focusing on the broad concepts, the details should be rather easy to grasp
- Focusing on the details rather than broad concepts will make this course very difficult
- Read textbook as a support document even when lecture material is not concentrating on specific details in the book
- Although discussing 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
- Seek help from the instructor or the TAs if help is needed on any topic
- Ask questions in class on any concepts that are not clearly understood

Equal Access Policy

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

Participation in any classes or laboratories, turning in of homework, or taking any exams 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 contribute. Successful completion of ALL laboratory experiments 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



Be aware of safety even when operating in a virtual environment !

Due Dates and Late Reports

Homework assignments will be posted on the class WEB site and turned in on Canvas

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

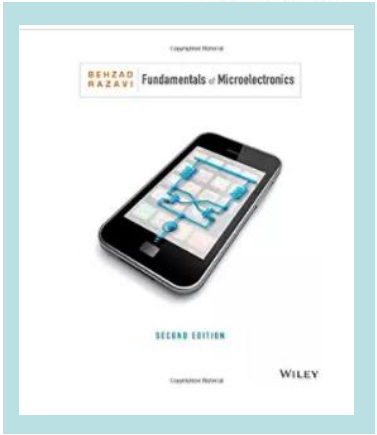
www.mosis.com

From MOSIS WEB site Aug 26, 2019

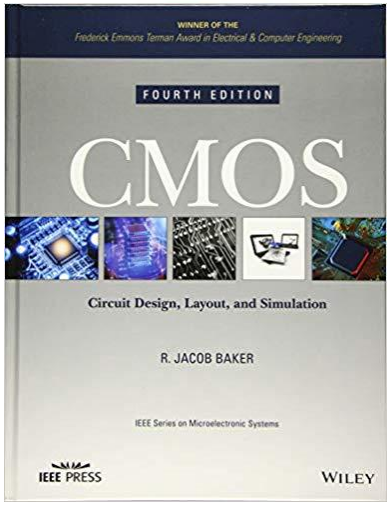
Effective immediately, MOSIS continues to support ON Semi B5 0.5 micron process (formally C5) for VLSI design classes for undergraduate courses under new MOSIS University Support Program. This will be the only free fabrication technology going forward.

Reference Texts:

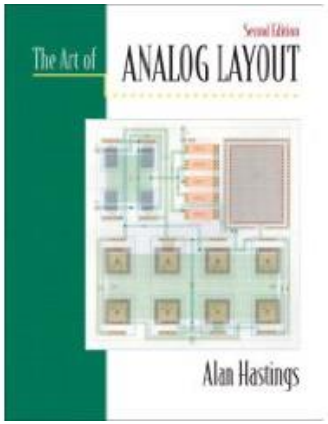
Fundamentals of Microelectronics
by B. Razavi, Wiley, 2013



CMOS Circuit Design, Layout, and Simulation (4th Edition)
by Jacob Baker, Wiley-IEEE Press, 2019.

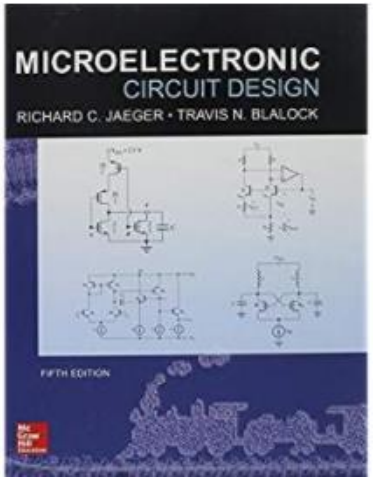


The Art of Analog Layout
by Alan Hastings, Prentice Hall, 2005

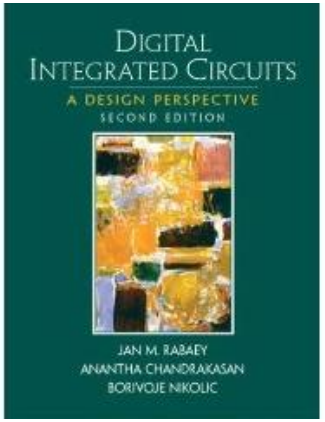


Reference Texts:

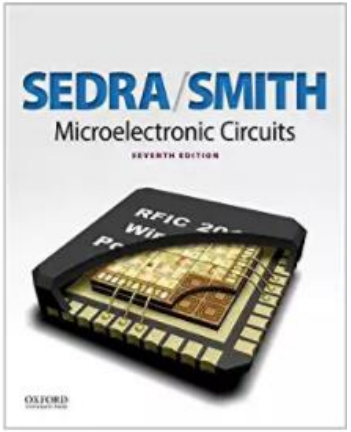
Microelectronic Circuit Design (4th edition)
By Richard Jaeger and Travis Blalock,
McGraw Hill, 2015



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

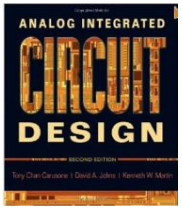


Microelectronic Circuits (7th Edition)
by Sedra and Smith, Oxford, 2014

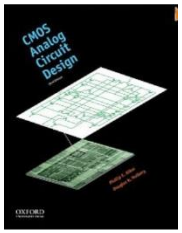


Other useful reference texts in the VLSI field:

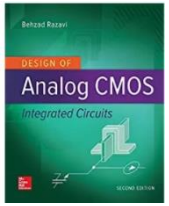
Analog Integrated Circuit Design (2nd edition)
by T. Carusone, D. Johns and K. Martin, Wiley, 2011



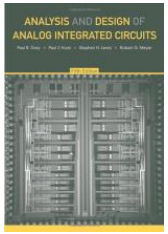
CMOS Analog Circuit Design (3rd edition)
by Allen and Holberg, Oxford, 2011.



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



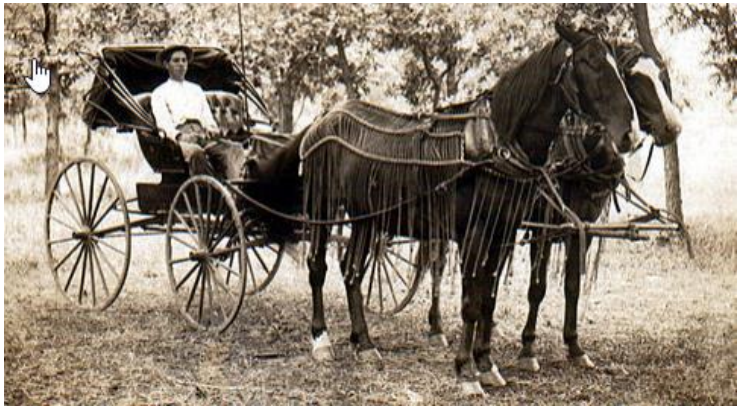
Untethered Communication Policy

Use them !

Hearing them ring represents business opportunity !

Technology Revolution

Obsolete or Current?



Technology Revolution

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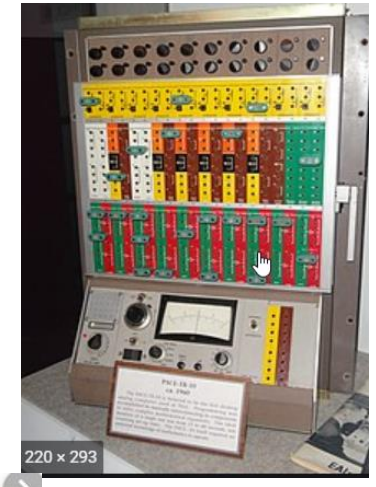

Technology Revolution

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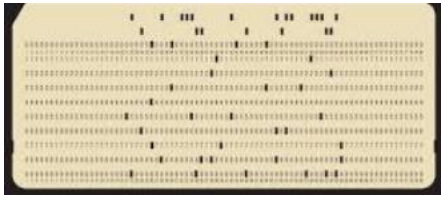
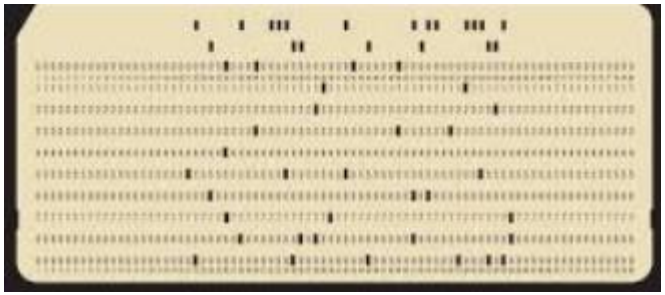
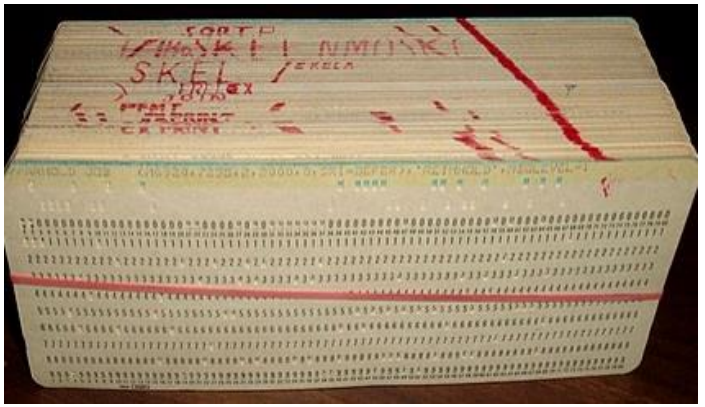
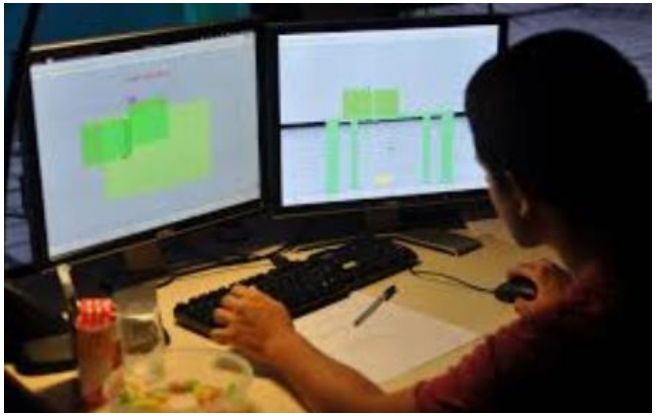


Technology Revolution

Obsolete or Current?

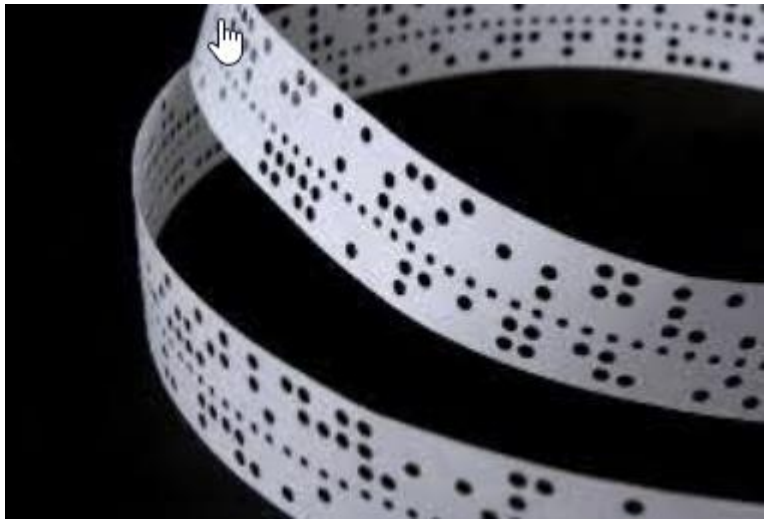






Technology Revolution

Obsolete or Current?



Technology Revolution

Obsolete or Current?

Technology Revolution

Obsolete or Current?

The end of Blu-ray | ZDNet

https://www.zdnet.com › article › the-end-of-blu-ray

Feb 25, 2019 - Thanks to the rise of streaming, Samsung is discontinuing its Blu-**ray** and 4K Blu-**ray** player lines. That's lousy news for people who love older ...

Over 10 years ago, Samsung released the first commercial Blu-ray video disc player. Within a few years, Samsung and other Blu-ray OEMs had defeated their rival HD DVD manufacturers. They were set to dominate the video world. Then, streaming came along and everything changed. Recently, Samsung told *CNET* that, "Samsung will no longer introduce new Blu-ray or 4K Blu-ray player models in the US market."

Technology Revolution

Obsolete or Current?

Blu-ray is dead.

It's not often that an industry's leading OEM quits, but that's what Samsung has done. Samsung had 37 percent of the market, followed by Sony at 31 percent and LG at 13 percent according to market research firm NPD Group. On Amazon, Samsung had four of Amazon's 10 best-selling Blu-ray players including the most popular model.

With its demise, Blu-ray follows Laserdisc, BetaMax, and VHS VCRs into the second-hand stores. DVDs may soon follow. Ted Sarandos, Netflix's longtime head of content told Variety, even though Netflix still has three-million DVD subscribers, "We never spent one minute trying to save the DVD business."

Why? It's all because of streaming.

Technology Revolution

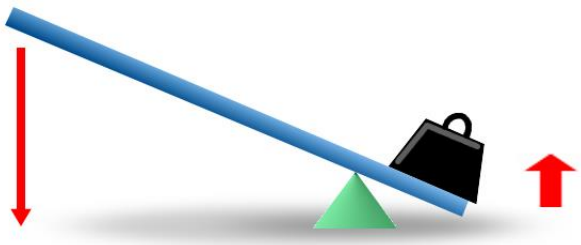
Obsolete or Current?

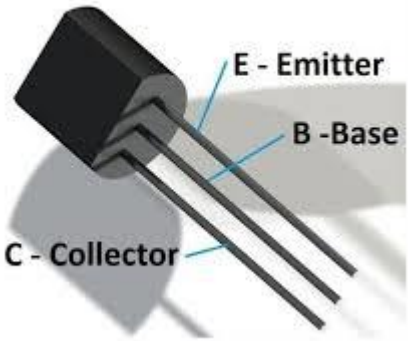
Technology Revolution

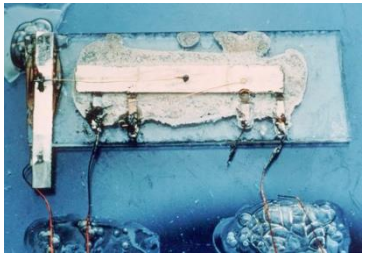
Obsolete or Current?

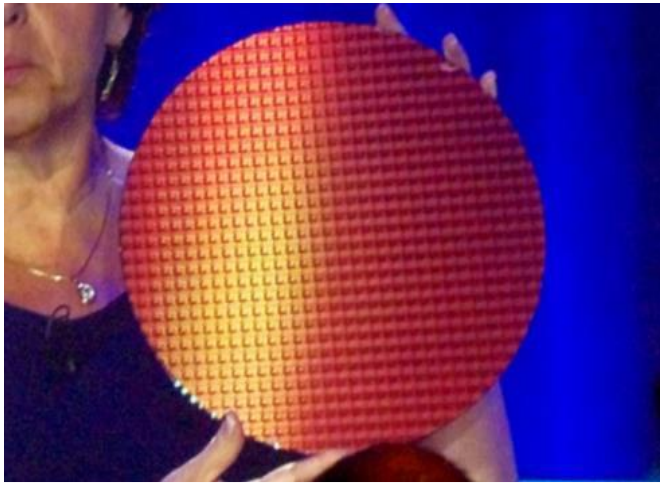
Technology Revolution

Obsolete or Current?



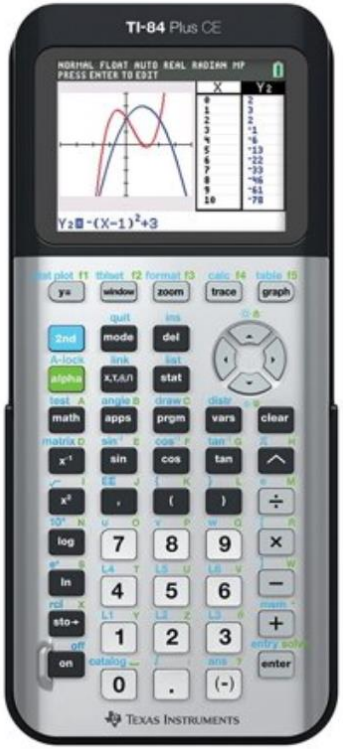






Technology Revolution

Obsolete or Current?



Graphing calculator

Computing engine

A graphing calculator is a handheld computer that is capable of plotting graphs, solving simultaneous equations, and performing other tasks with variables. Wikipedia

Calculation supported: Equation

Operation supported: Graph of a function, Computer algebra system, Programming

Purpose: Solving simultaneous equations, Plotting graphs

Application: Education, Engineering

Introduced in school level: High school, GCE Advanced Level

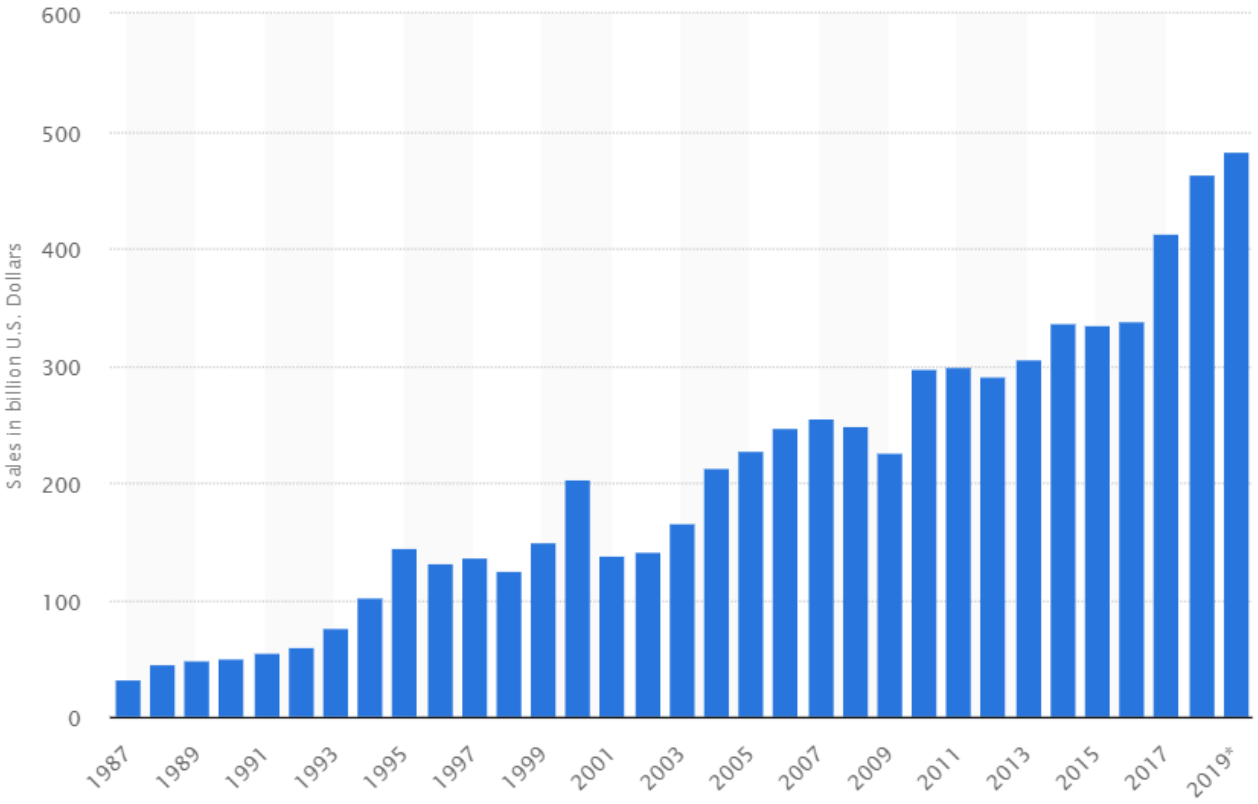
The Semiconductor Industry

(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

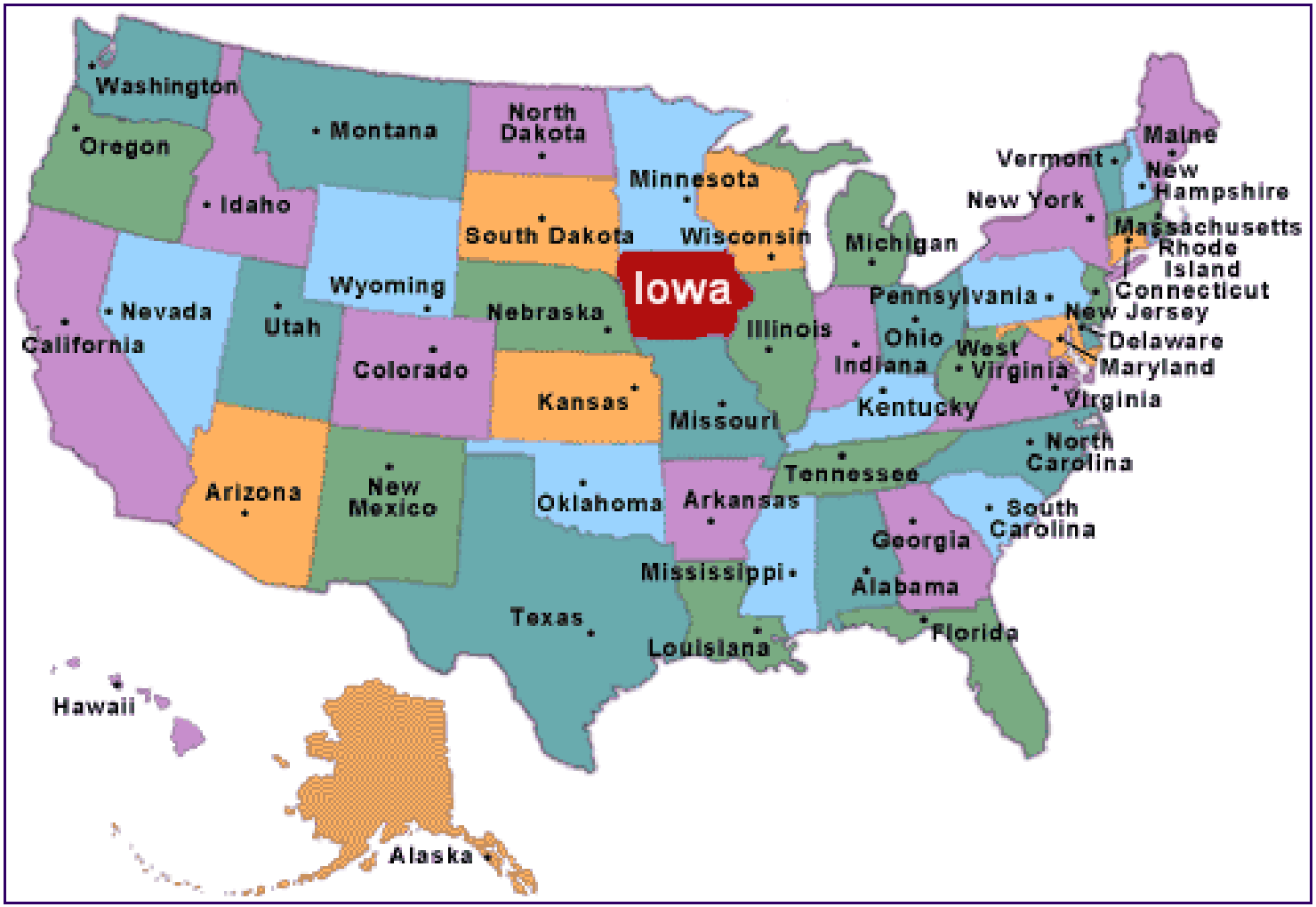
Semiconductor sales do not include the sales of the electronic systems in which they are installed and this marked is much bigger !!

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**

Based upon Jan 12, 2020 markets in Boone Iowa

	Corn	Soybeans
Jan 2020	3.69	8.80

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**	**$8.1**
United States	**12**	**$44**
World	**23**	**$85**

Soybean Production

	Bushels (Millions)	Value (Billion Dollars)
Iowa	**340**	**$3.0**
United States	**3,100**	**$27**
World	**8,000**	**$70**

Projected world 2019 semiconductor sales of $483B about 312% 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 (over 3X)

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

And the electronics industry which embeds the semiconductor devices is much larger

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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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%
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ElectronicsWeekly.com

Top 10 Semiconductor Sales Leaders 2016-2019

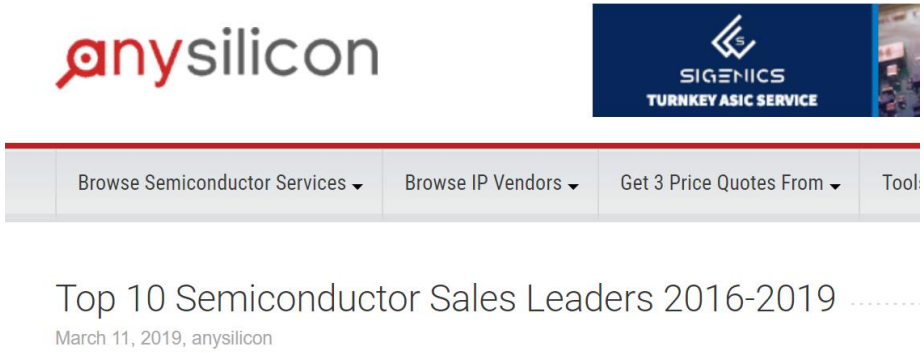
March 11, 2019, anysilicon

Top 10 Worldwide Semiconductor Sales Leaders

	2016		2017			2018			2019F		
Rank	Company	Sales ($B)	Company	Sales ($B)	Change	Company	Sales ($B)	Change	Company	Sales ($B)	Change
1	Intel	$57.0	Samsung	$65.9	48.8%	Samsung	$78.5	19.2%	Intel	$70.6	1.0%
2	Samsung	$44.3	Intel	$61.7	8.2%	Intel	$69.9	13.2%	Samsung	$63.1	-19.7%
3	TSMC (2)	$29.5	TSMC (2)	$32.2	9.1%	SK Hynix	$36.8	37.6%			
4	Qualcomm (1)	$15.4	SK Hynix	$26.7	79.5%	TSMC (2)	$34.2	6.4%			
5	Broadcom (1)	$15.2	Micron	$23.9	76.7%	Micron	$31.0	29.6%			
6	SK Hynix	$14.9	Broadcom (1)	$17.8	16.9%	Broadcom (1)	$18.5	3.7%			
7	Micron	$13.5	Qualcomm (1)	$17.0	10.5%	Qualcomm (1)	$16.4	-3.8%			
8	TI	$12.5	TI	$13.9	11.3%	Toshiba*	$14.9	12.1%			
9	Toshiba	$10.9	Toshiba	$13.3	21.9%	TI	$14.9	6.8%			
10	NXP	$9.5	Nvidia (1)	$9.4	36.1%	Nvidia (1)	$12.0	27.1%			
Top 10 Total ($B)		$222.8	—	$281.9	26.5%	—	$327.0	16.0%			
Semi Market ($B)		$364.0	—	$445.2	22.3%	—	$504.1	13.2%	—	$468.9	-7.0%

Source: IC Insights (1) Fabless (2) Pure-Play foundry *Includes Toshiba Memory

Why did Samsung's position change so much?



IC Insights is currently updating its 2019-2023 semiconductor market forecasts that will be presented later this month in the March Update, the first monthly Update to the 500-page, 2019 edition of The McClean Report—A Complete Analysis and Forecast of the Integrated Circuit Industry (released in January 2019).

For 2019, a steep 24% drop in the memory market is forecast to pull the total semiconductor market down by 7%. With 83% of Samsung's semiconductor sales being memory devices last year, the memory market downturn is expected to drag the company's total semiconductor sales down by 20% this year. Although Intel's semiconductor sales are forecast to be relatively flat in 2019, the company is poised to regain the number 1 semiconductor supplier ranking this year (Figure 1), a position it held from 1993 through 2016.

Applications of Electronic Devices

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

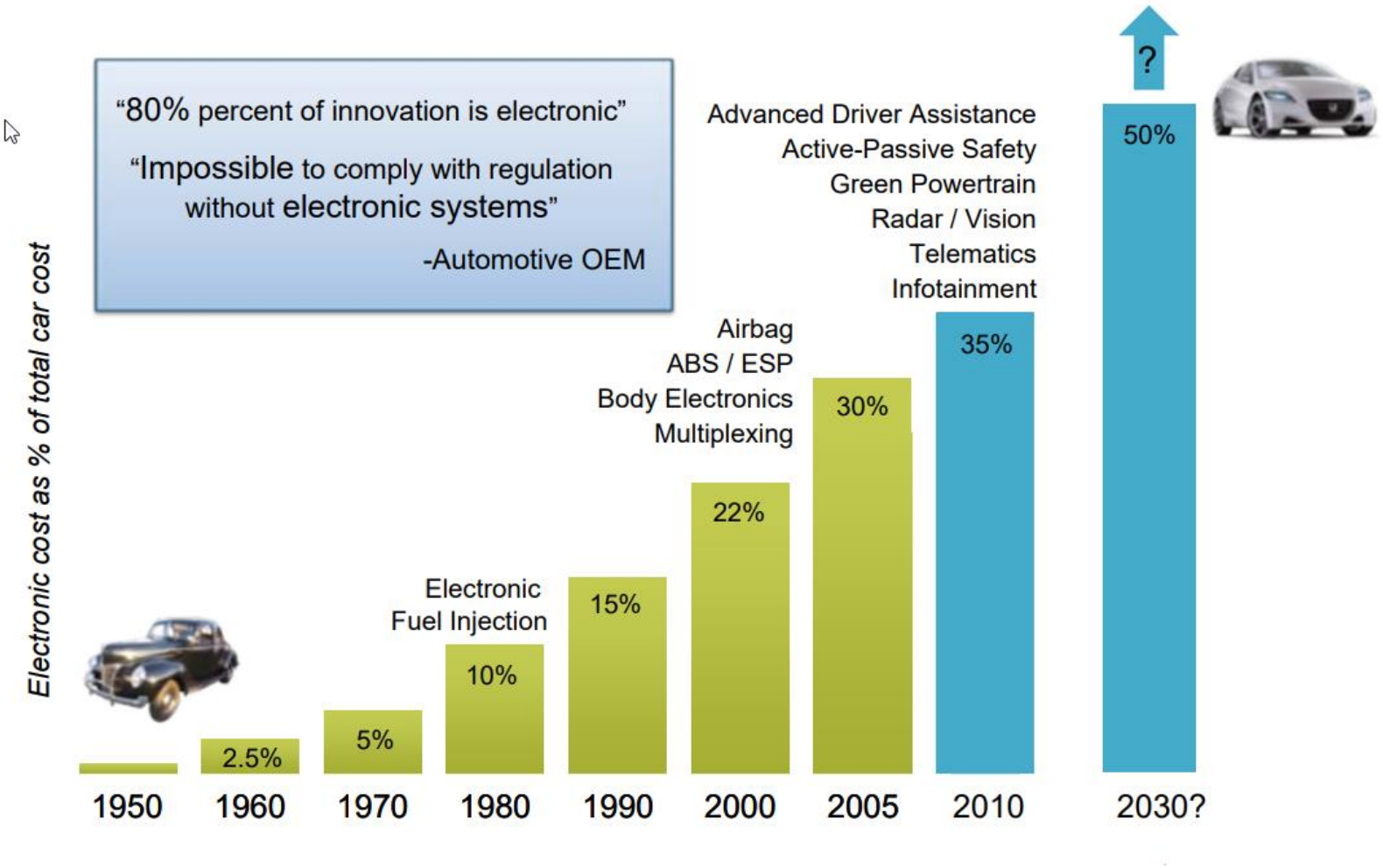
Applications often incorporate several classical application areas

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

Electronic circuit designers must understand system operation to provide useful electronic solutions

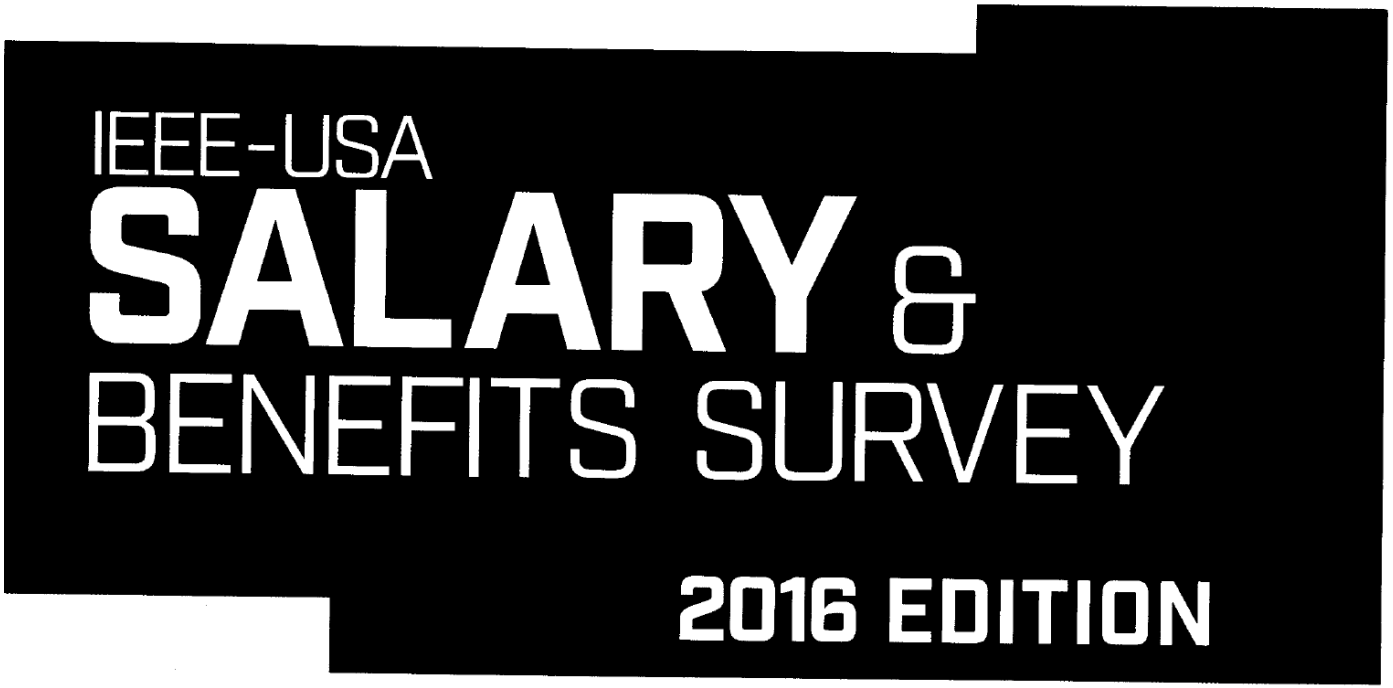
Is an automobile an electronics “gadget”?

Automotive Electronic Content Growth



Rewards in the Electronics Field

Can engineers working in the semiconductor electronics field make a good living?



2015 Primary Income by Primary Area of Technical Competence

	Number of Cases	*Lowest Decile*	*Lower Quartile*	*Median*	*Upper Quartile*	*Highest Decile*
TOTAL	7,391	$79,200	$103,000	$135,000	$173,000	$223,000
CIRCUITS AND DEVICES	1,127	$85,000	$110,000	$144,700	$182,878	$240,000
Circuits and Systems	416	$79,750	$100,991	$130,000	$165,000	$210,000
Components, Packaging and Manufacturing Technology	94	$103,200	$120,188	$153,850	$190,700	$258,800
Electronic Devices	239	$80,000	$105,034	$141,458	$186,372	$235,240
Lasers and Electro-Optics	79	$83,800	$112,915	$150.000	$184,000	$222,800
Solid-State Circuits	277	$105,030	$134,000	$165,000	$204,700	$265,168
Other	25	$72,380	$107,000	$136,000	$208,000	$332,175
COMMUNICATIONS TECHNOLOGY	581	$87,000	$114,000	$152,500	$196,000	$250,000
Broadcast Technology	46	$64,500	$97,500	$141,500	$198,000	$326,250
Communications	419	$87,400	$114,945	$153,000	$193,289	$246,370
Consumer Electronics	42	$94,150	$105,750	$156,500	$188,750	$256,500
Vehicular Technology	21	-	-	-	-	-
Other	61	$93,441	$122,400	$163,000	$208,099	$270,000
COMPUTERS	1,545	$80,000	$103,500	$138,941	$180,000	$233,614
Hardware	246	$90,000	$110,000	$143,702	$182,625	$254,261
Non-Internet Software Development	591	$80,000	$101,000	$136,000	$176,928	$226,000
Non-Internet Systems Analysis/Integration	179	$83,800	$102,583	$130,000	$173,726	$221,850
Non-Internet Software Applications including Database Admin.	90	$65,260	$100,415	$132,500	$165,825	$222,500
Internet/Web Development/Applications	220	$73,538	$106,875	$139,800	$181,438	$256,757
Other	224	$80,300	$108,172	$147,500	$181,875	$234,290
ELECTROMAGNETICS AND RADIATION	420	$84,900	$110,000	$137,912	$169,606	$204,655
Antennas and Propagation	103	$78,720	$116,100	$140,000	$172,000	$197,367
Electromagnetic Compatibility	65	$76,800	$96,000	$123,079	$155,000	$180,600
Magnetics	26	$90,500	$109,472	$145,000	$180,902	$241,000
Microwave Theory and Techniques	114	$79,200	$105,314	$133,526	$168,344	$200,650
Nuclear and Plasma Sciences	70	$87,660	$113,725	$139,000	$159,825	$192,660
Other	50	$102,000	$121,500	$150,000	$184,600	$220,000
ENERGY AND POWER ENGINEERING	1,597	$75,000	$94,450	$121,000	$152,000	$192,000

ENGINEERING AND HUMAN ENVIRONMENT	144	$73,868	$99,900	$132,667	$167,625	$220,728
Education	24	-	-	-	-	-
Engineering Management	87	$97,200	$116,000	$145,000	$180,000	$230,480
Professional Communication	0	-	-	-	-	-
Reliability	15	-	-	-	-	-
Social Implications of Technology	8	-	-	-	-	-
Other	14	-	-	-	-	-
INDUSTRIAL APPLICATIONS	340	$79,900	$100,000	$126,600	$160,000	$210,000
Dielectrics and Electrical Insulation	16	-	-	-	-	-
Industry Applications	149	$87,660	$108,400	$130,000	$166,220	$211,460
Instrumentation and Measurement	91	$68,000	$92,124	$118,000	$144,985	$180,000
Power Electronics	59	$81,835	$102,500	$130,000	$160,500	$208,400
Other	25	$99,780	$120,000	$143,000	$210,000	$235,145
SIGNALS AND APPLICATIONS	532	$94,100	$114,263	$142,792	$180,000	$223,000
Aerospace and Electronic Systems	162	$90,300	$113,010	$147,500	$179,250	$216,895
Geoscience and Remote Sensing	47	$96,600	$113,379	$153,200	$198,000	$220,531
Oceanic Engineering	13	-	-	-	-	-
Signal Processing	243	$95,046	$116,237	$141,200	$179,000	$230,649
Ultrasonics, Ferroelectrics and Frequency Control	36	$96,750	$117,197	$136,000	$167,657	$239,500
Other	30	$75,020	$106,250	$130,926	$178,277	$205,100
SYSTEMS AND CONTROL	689	$74,800	$98,000	$130,000	$165,000	$209,582
Control Systems	270	$72,000	$94,625	$122,183	$155,110	$197,000
Engineering in Medicine and Biology	124	$88,002	$113,847	$143,500	$182,000	$229,600
Industrial Electronics	62	$71,550	$89,250	$118,517	$154,113	$194,188
Information Theory	10	-	-	-	-	-
Robotics and Automation	129	$73,106	$92,842	$123,000	$154,609	$188,520
Systems, Man and Cybernetics	64	$75,000	$120,000	$146,946	$184,250	$222,800
Other	47	$97,600	$117,250	$154,000	$182,000	$224,960
OTHER	346	$79,000	$103,000	$131,424	$178,000	$235,000

2015 Primary Income by Primary Area of Technical Competence

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ENERGY AND POWER ENGINEERING	1,597	$75,000	$94,450	$121,000	$152,000	$192,000

Opportunities in the Electronics Field

- A lot has happened in the field in the past 4 decades
- Are there still opportunities?

But be realistic about the difference between what can be done and what can be done profitably

How many of you stream high definition video on smart phones?

If not, how many would like to?

Consider Television Sets and Monitors

8K UHD Television

Pixels: 7680 Horizontal and 4320 Vertical

Samsung - 55" Class - LED - Q900 Series - 4320p - Smart - 8K UHD TV with HDR

Model: QN55Q900RBFXZA **SKU:** 6355633

4.8 (19 Reviews) | 12 Expert Reviews | 7 Answered Questions

Price Match Guarantee

$2,499.99

Save $500

Was $2,999.99

Hot offer Save $50-$200

But: No 8K media or broadcast channels available in the US and none on the horizon at this time (Jan 2020)!

Consider Television Sets and Monitors

4K UHD Television

Pixels: 3840 Horizontal and 2160 Vertical

TCL - 55" Class - LED - 5 Series - 2160p - Smart - 4K UHD TV with HDR - Roku TV

Model: 55S525 **SKU:** 6358918

4.5 (126 Reviews) | 50 Answered Questions

Price Match Guarantee

$329.99

Save $120

Was $449.99

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

(to keep reasonable bandwidth without throttling)

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 = 43 TB

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

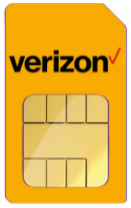
Audio:

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

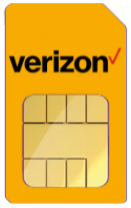
What does data really cost today (Aug 2021)?



Verizon 5GB shared data: from $55 per month

Verizon's shared data plans start with a 5GB allowance plan for $55 a month. The pric
but it's worth noting that 5GB doesn't go a long way, so if you're planning on sharing
make sure you're both only using it for browsing and checking emails. This plan incluc
the Verizon premium network, but no streaming service or cloud storage perks.

1-line: $55/mo | **2-line:** $80/mo | **3-line:** $105/mo



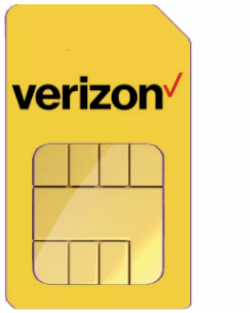
Verizon 10GB shared data: from $65 per month

The second shared data plan is a 10GB option, which we'd recommend for most peop
their plan across multiple users or devices. Again, 10GB doesn't go that far, but it's a f
helping for most non-streaming tasks. This plan includes full 5G access on the Verizor
but no streaming service or cloud storage perks.

1-line: $65/mo | **2-line:** $90/mo | **3-line:** $115/mo

Effective data rates: $2/GB

Is it really unlimited?



TECHRADAR RECOMMENDS

Verizon Play More Unlimited: $80/mo for 1-line

Verizon's Play More Unlimited is Verizon's main consumer-focused postpaid plan. It sits right in the middle cost-wise but features full unlimited 5G access, priority premium network access, and a full subscription to Hulu, Disney+, and even ESPN+. It's definitely quite pricey, but you're getting a ton of great perks here as well as unlimited and reliable access to some of the best data speeds in the country.

1-line: $80/mo | **2-line:** $140/mo | **3-line:** $165/mo

VIEW DEAL

Yes – but …

What about throttling?

Verizon has 3 levels of unlimited data plans. The cheapest one has the possibility of being "throttled" AT ANY TIME there is congestion on the local towers. The mid-tier has no throttling until you have used at least 22 GB in a month on a line. The highest tier has no throttling until you have used at least 75 GB in a month on a line.

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 = 3.1 TB

Total cost: $10,745

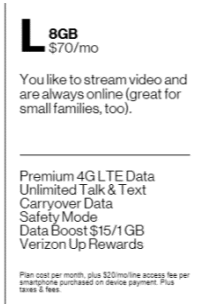
Moving audio and video data is still expensive and still challenging !

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

Stay Safe and Stay Healthy !

End of Lecture 1