

EE 330

Spring 2022



Integrated Electronics

Lecture Instructors:

Randy Geiger

2133 Coover

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294-7745

Course Web Site:

<http://class.ece.iastate.edu/ee330/>

Lecture: MWF 8:50 –9:40

Lab:	Sec 1	Tues	8:00 - 10:50	TA: Nick Moser/Julio Torres
	Sec 2	Tues	5:10 - 8:00	TA: Julio Torres/Patricia Tutuani
	Sec 3	Wed	3:20 - 6:10	TA: Patricia Tutuani
	Sec 4	Thur	3:10 - 6:00	TA: Nick Moser/Patricia Tutuani

Labs start this week !

HW Assignment 1 will be posted later today and is due on Monday

Photo courtesy of the director of the National Institute of Health (NIH)



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:

1. Nick Moser nsmoser@iastate.edu
2. Julio Torres jgtorres@iastate.edu
3. Patricia Tutuani ptutuani@iastate.edu

Instructor Access:

- Office Hours
 - Tuesday, Thursday, Friday 11:15-12:00
 - By appointment at other times
- Email
 - rlgeiger@iastate.edu
 - Include **EE 330** in subject
- Class Zoom Link

<https://iastate.zoom.us/j/92142125293>

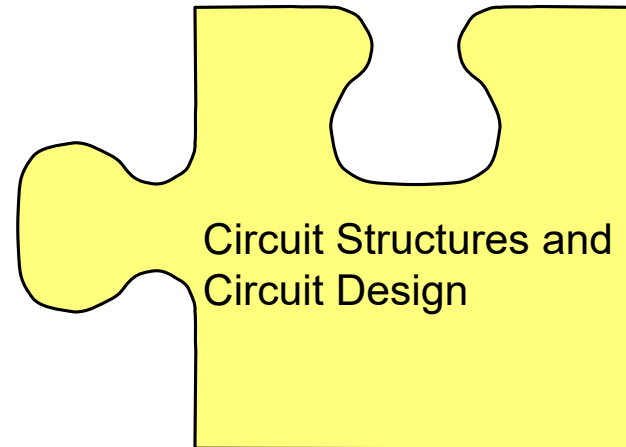
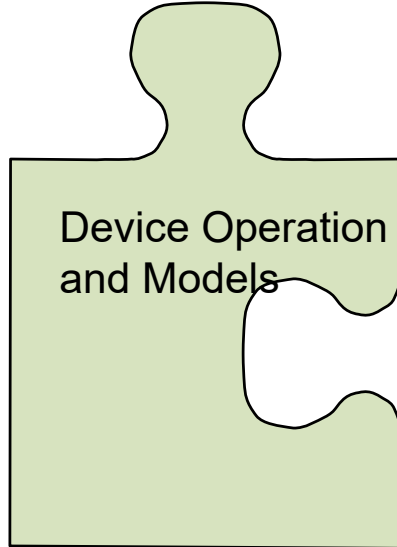
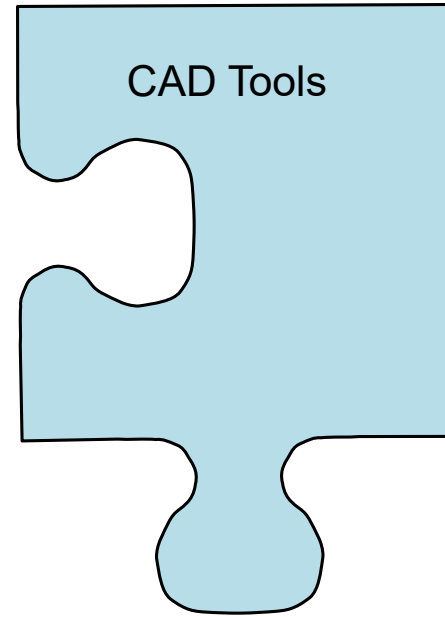
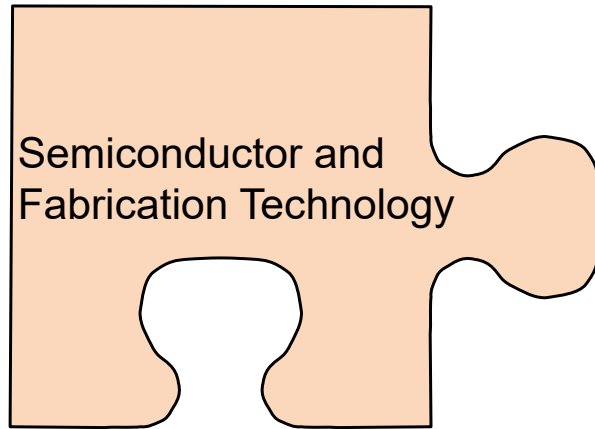
Catalog Description

EE 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

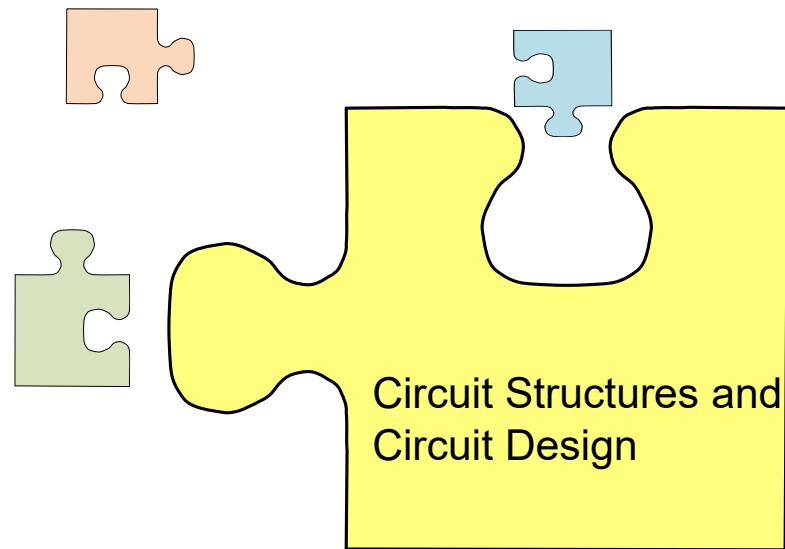
- Almost all electronic circuits are, at the most fundamental level, an interconnection of transistors and some passive components such as resistors, capacitors, and inductors
- For many years, electronic systems involved placing a large number of discrete transistors along with passive components on 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 !

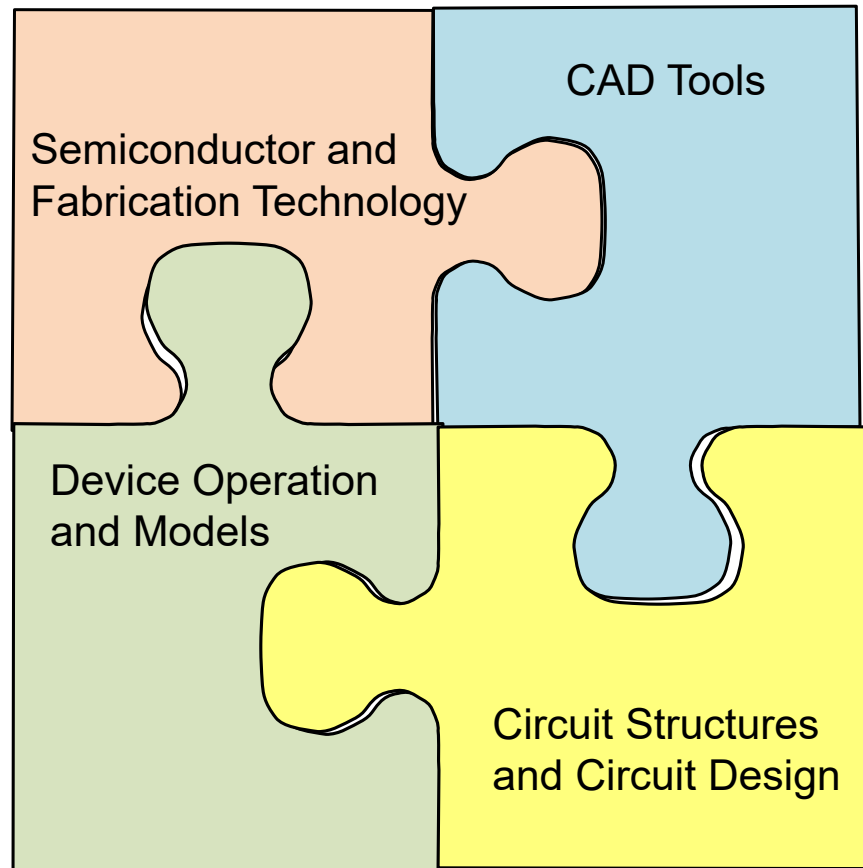
How Electronics was Approached for Decades



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



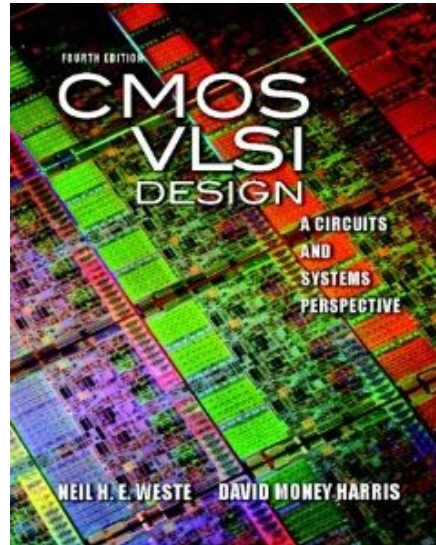
The sequencing of laboratory experiments has been intentionally structured so that on some topics, a laboratory investigation will lead a topic in the classroom and in others it will follow

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

Academic Misconduct

Academic misconduct will not be tolerated in this course

- Academic misconduct includes, but is not limited to, representing someone else's work as your own. Some examples of academic misconduct include turning in homework solutions that are copied from someone else, turning in source code prepared by someone else, and copying solutions from someone else on exams.
- Academic misconduct also includes but is not limited to making postings or dissemination of course materials so that the poster or others can take advantage of the work of others. Specifically precluded is posting any homework or exam problems on any forums such as Chegg or accessing these forums to see if anyone else has posted or solved problems.

Those that violate the academic conduct guidelines will, at the discretion of the instructor, receive either a grade of 0 for the work where academic misconduct occurred or a grade of F for the course. A grade of F will be assigned to any student that is caught using electronic forums such as Chegg (either posting or accessing) during any exam.

The course will follow Iowa State University's policy on academic dishonesty. Anyone suspected of academic dishonesty will be reported to the [Office of Student Conduct](#).

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



- 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

Laboratory Safety



Due Dates and Late Reports

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

Homework assignments will usually be due at noon on Fridays but will be accepted without penalty up until 11:59 pm on the due date. In weeks where exams are scheduled or other situations arise, the homework assignment due times will be changed.

Laboratory reports are due at 11:59 p.m. on the day before the next laboratory experiment is scheduled. Reports will be turned in on Canvas. The last laboratory report will be due one week after the scheduled completion of the experiment.

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



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microelectronics fabrication

Production Solutions for IC Innovation

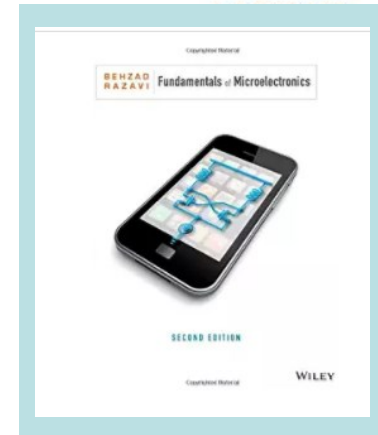
www.mosis.com

From MOSIS WEB site Aug 26, 2019

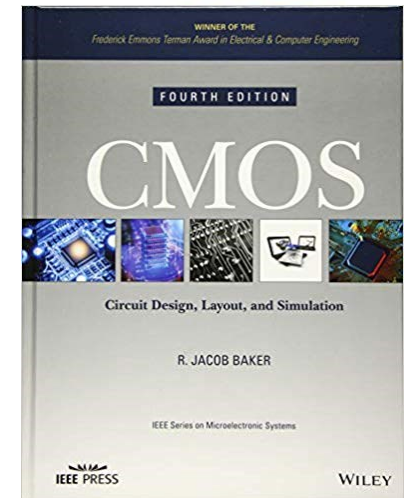
Effective immediately, MOSIS continues to support ON Semi B5 0.5 micron process (formally C5) for VLSI design classes for undergraduate courses under new MOSIS University Support Program. This will be the only free fabrication technology going forward.

Reference Texts:

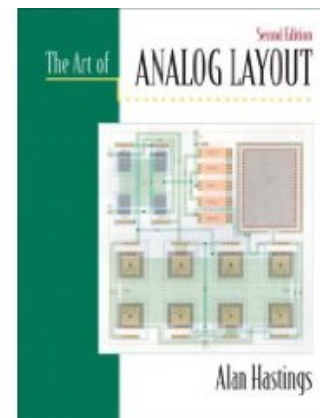
Fundamentals of Microelectronics
by B. Razavi, Wiley, 2013



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

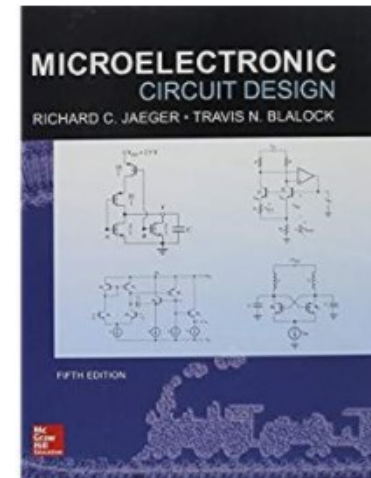


The Art of Analog Layout
by Alan Hastings, Prentice Hall, 2005

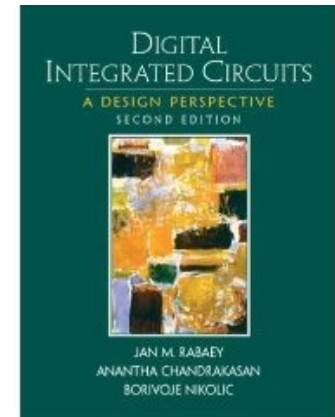


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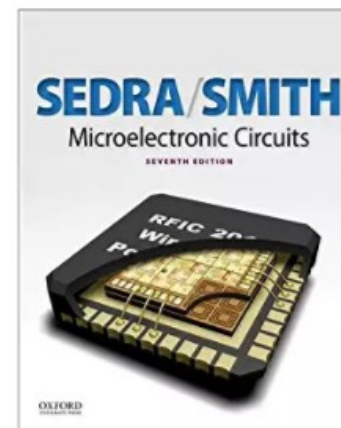
Microelectronic Circuit Design (4th edition)
By Richard Jaeger and Travis Blalock,
McGraw Hill, 2015



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

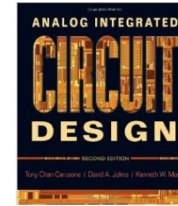


Microelectronic Circuits (7th Edition)
by Sedra and Smith, Oxford, 2014

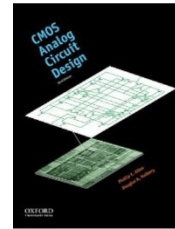


Other useful reference texts in the VLSI field:

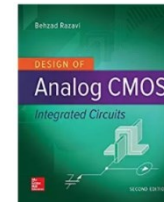
Analog Integrated Circuit Design (2nd edition)
by T. Carusone, D. Johns and K. Martin, Wiley, 2011



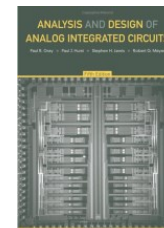
CMOS Analog Circuit Design (3rd edition)
by Allen and Holberg, Oxford, 2011.



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

Obsolete or Current?



Technology Revolution

Obsolete or Current?



Technology Revolution

Obsolete or Current?



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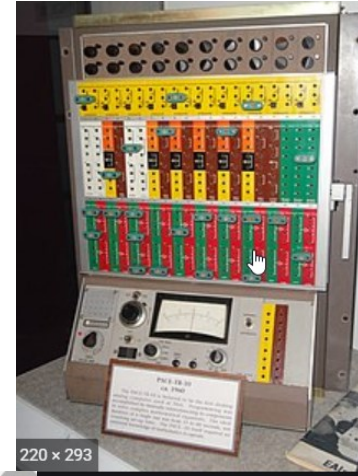
Technology Revolution

Obsolete or Current?



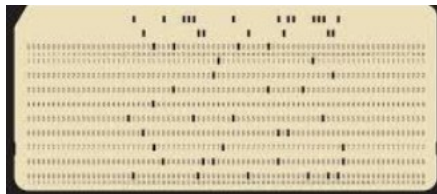
Technology Revolution

Obsolete or Current?



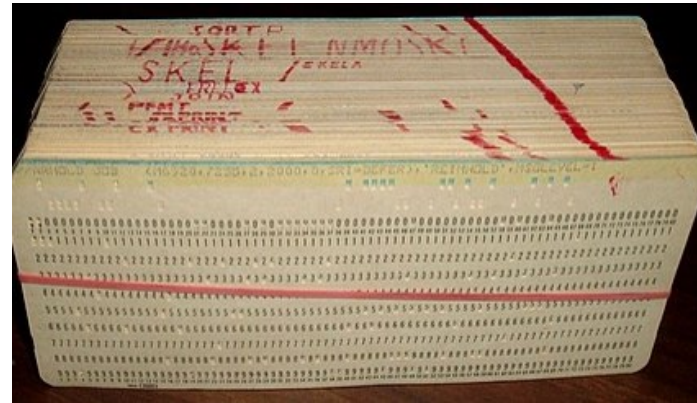
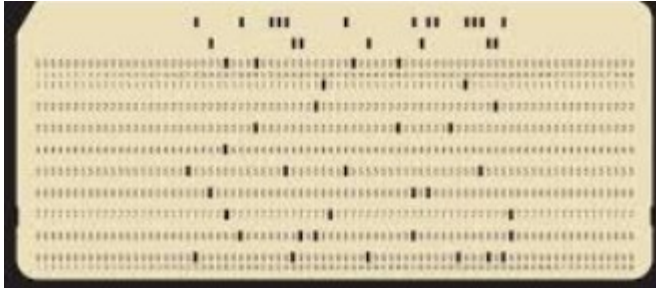
Technology Revolution

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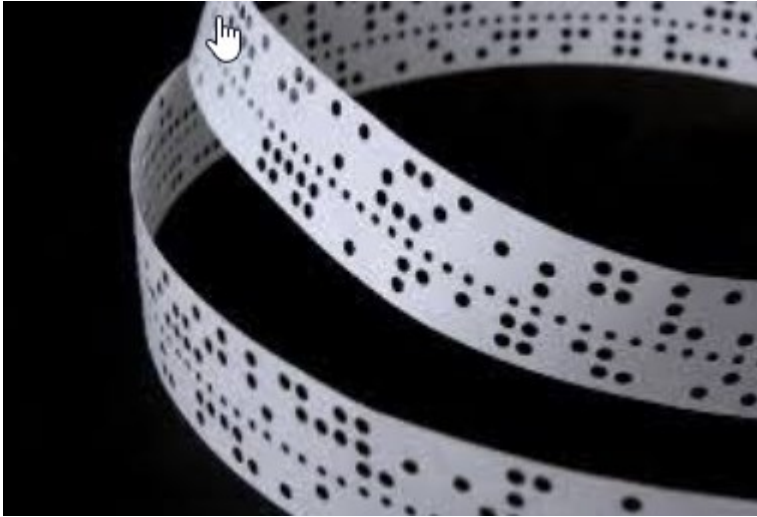
Technology Revolution

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.



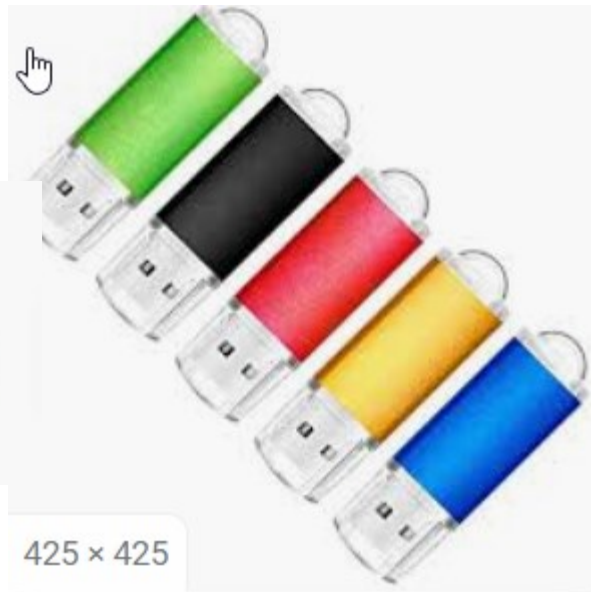
Technology Revolution

Obsolete or Current?



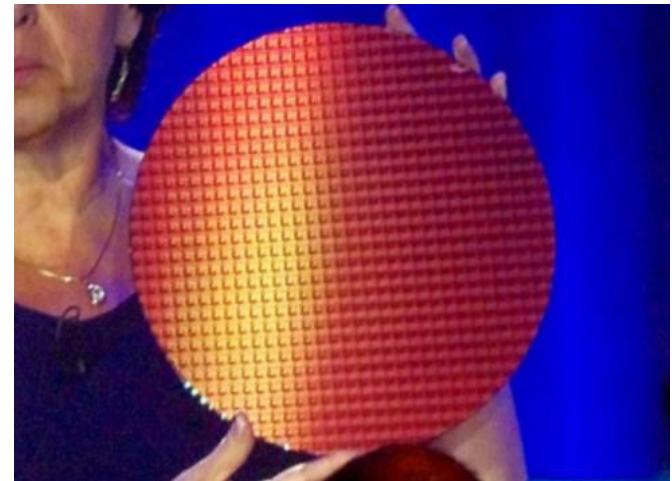
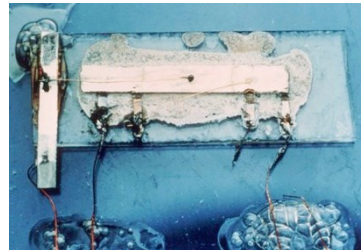
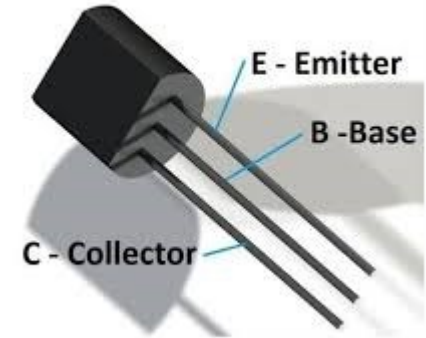
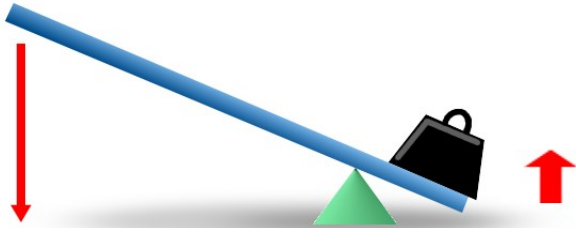
Technology Revolution

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



Technology Revolution

- Electronics technology is the driving factor in this technology revolution
- Electronics technology will play an even larger role in the technology revolution of the next two decades !



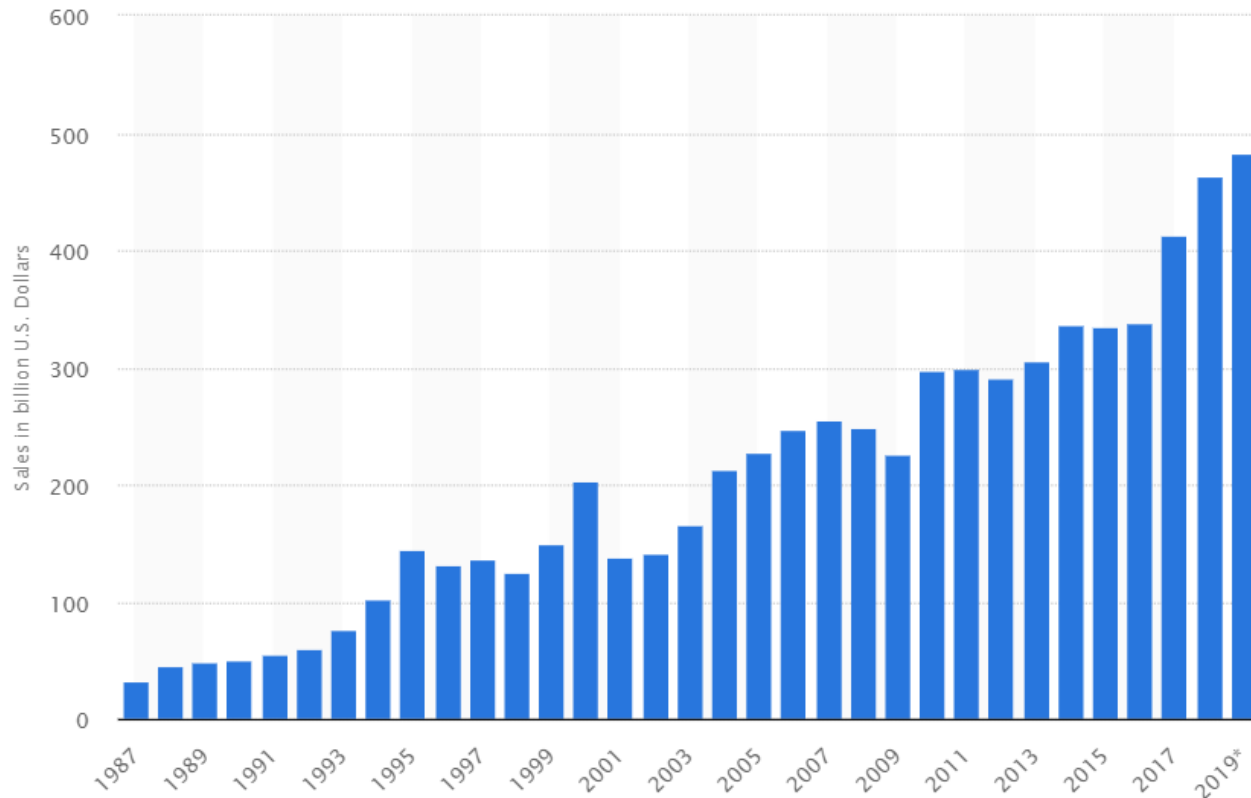
The Semiconductor Industry

(just the “chip” part of the business)

How big is it ?

How does it compare to other industries?

How big is the semiconductor industry?



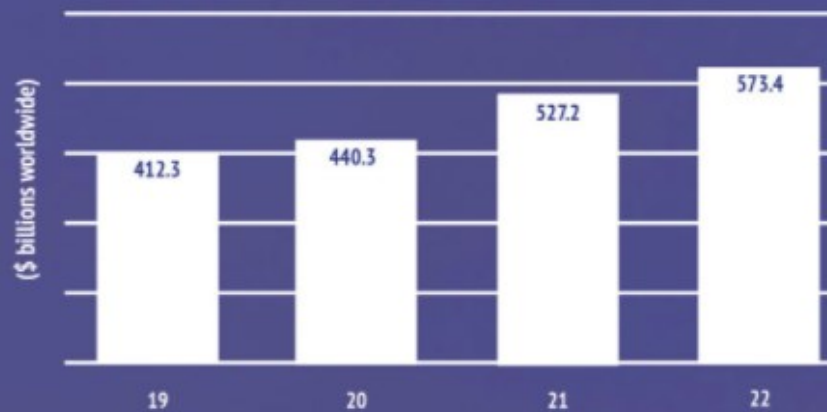
Projected at \$483 Billion in 2019

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

How big is the semiconductor industry?

The global semiconductor market will grow nearly 20 per cent in 2021
Source: WSTS

Chip market pushes upward



How big is the semiconductor industry?

Latest News



Global Semiconductor Sales Increase 24% Year-to-Year in October; Annual Sales Projected to Increase 26% in 2021, Exceed \$600 Billion in 2022

Friday, Dec 03, 2021, 4:30pm

by Semiconductor Industry Association

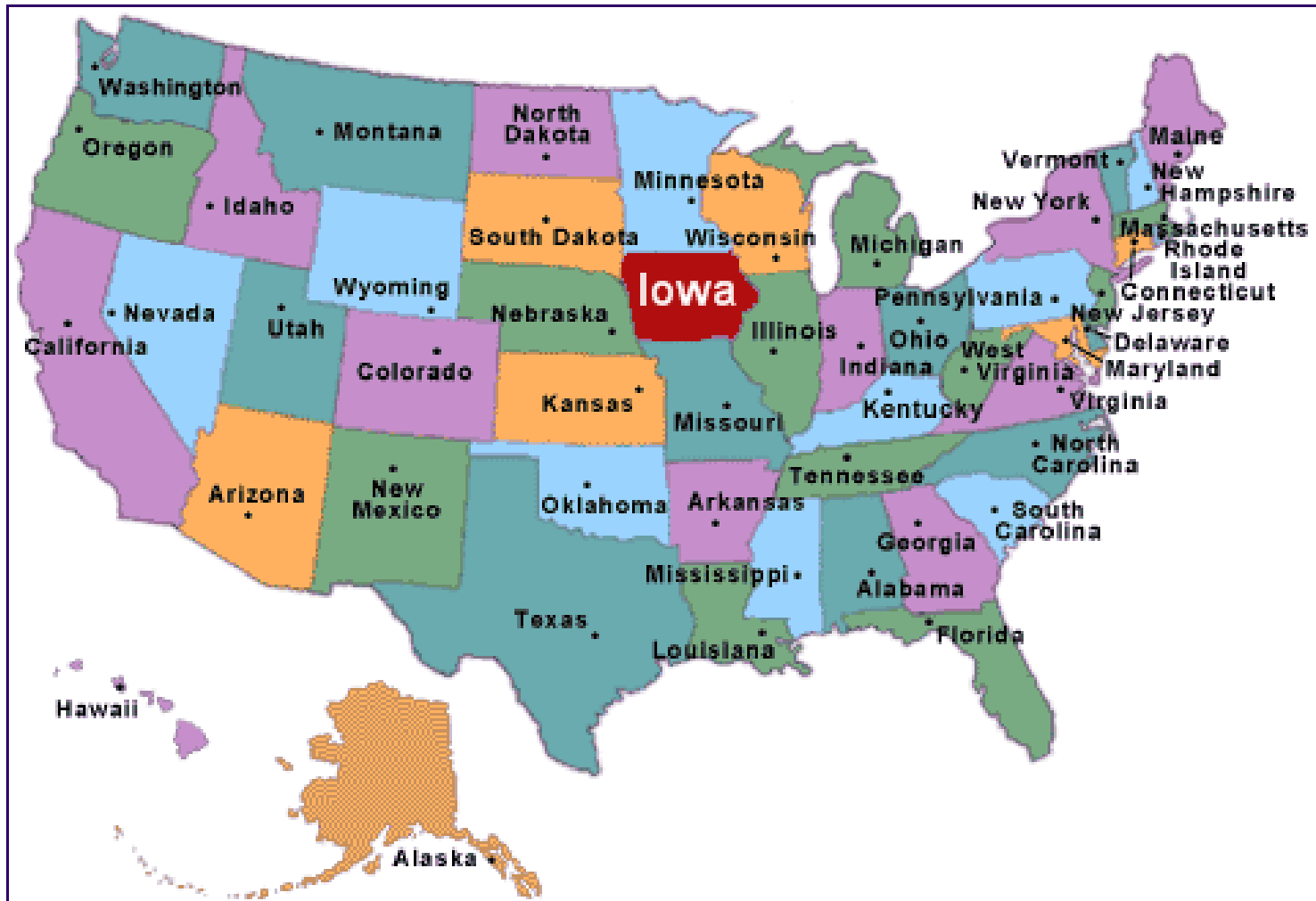
- Annual sales around \$600B in 2022
- 25% annual growth rate
- Unprecedented demand for engineers in the field

The Semiconductor Industry

How big is it ?

How does it compare to Iowa-Centric Commodities?

Iowa-Centric Commodities



Iowa-Centric Commodities

In the United States, Iowa ranks:

First in Corn production

First in Soybean production

First in Egg production

First in Hog production

Second in Red Meat production

<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



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

Based upon Jan 12, 2020 markets in Boone Iowa

Corn

Soybeans

Jan 2020

3.69

8.80



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

Based upon Jan 19, 2022 markets in Boone Iowa

	Corn	Soybeans
Jan 2020	5.90	13.30

These markets are extremely high at this time

Value of Agricultural Commodities

(Based upon commodity prices in Boone Iowa on Jan 19, 2022)

(simplifying assumption: value constant around world)

Corn Production

	Bushels (Billions)	Value (Billion Dollars)
Iowa	2.2	\$13
United States	12	\$71
World	23	\$136

Soybean Production

	Bushels (Millions)	Value (Billion Dollars)
Iowa	340	\$4.5
United States	3,100	\$41
World	8,000	\$106

Projected world 2022 semiconductor sales of \$600B about 250% 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 \$600B/Year and growing

How does it compare to Iowa-Centric Commodities?

Larger than major agricultural commodities (over 2.5X)

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

The Key Players

Table 1. Top 10 Semiconductor Vendors by Revenue, Worldwide, 2020 (Millions of U.S. Dollars)

2020 Rank	2019 Rank	Vendor	2020 Revenue	2020 Market Share (%)	2019 Revenue	2019-2020 Growth (%)
1	1	Intel	72,759	15.6	67,754	7.4
2	2	Samsung Electronics	57,729	12.4	52,389	10.2
3	3	SK hynix	25,854	5.5	22,297	16.0
4	4	Micron Technology	22,037	4.7	20,254	8.8
5	6	Qualcomm	17,632	3.8	13,613	29.5
6	5	Broadcom	15,754	3.4	15,322	2.8
7	7	Texas Instruments	13,619	2.9	13,364	1.9
8	13	MediaTek	10,988	2.4	7,958	38.1
9	16	NVIDIA	10,643	2.3	7,331	45.2
10	14	KIOXIA	10,374	2.2	7,827	32.5
		Others (outside top 10)	208,848	44.8	194,228	7.5
		Total Market	466,237	100.0	422,337	10.4

Source: Gartner (April 2021)

Note: Sales of Intel alone exceeds value of all of the corn produced in the US

Note: Society has a monstrous appetite for electronic devices and gadgets

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

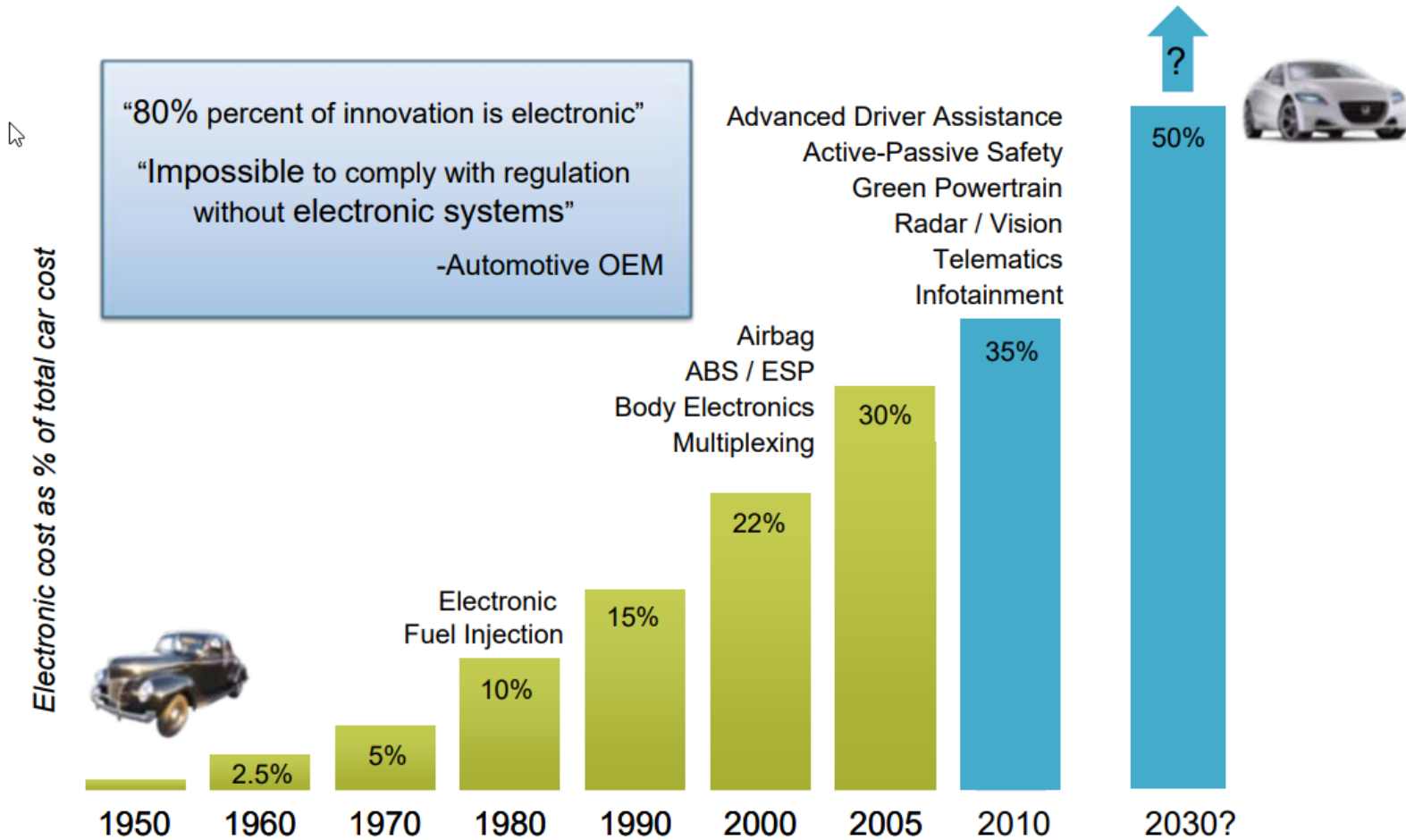
Large number (billions) of devices (transistors) in many applications

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

	<i>Number of Cases</i>	<i>Lowest Decile</i>	<i>Lower Quartile</i>	<i>Median</i>	<i>Upper Quartile</i>	<i>Highest Decile</i>
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

	<i>Number of Cases</i>	<i>Lowest Decile</i>	<i>Lower Quartile</i>	Median	<i>Upper Quartile</i>	<i>Highest Decile</i>
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

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

Unfortunately, **there's no way to filter 8K content** as there is with 4K or HDR videos (not yet, anyway). No current streaming services like Netflix, Disney+, Apple TV, or Amazon Prime Video offer any native 8K content. You cannot currently stream 8K on demand from any of the major streaming services. Jan 5, 2022

Consider Television Sets and Monitors

8K UHD Television

Pixels: 7680 Horizontal and 4320 Vertical

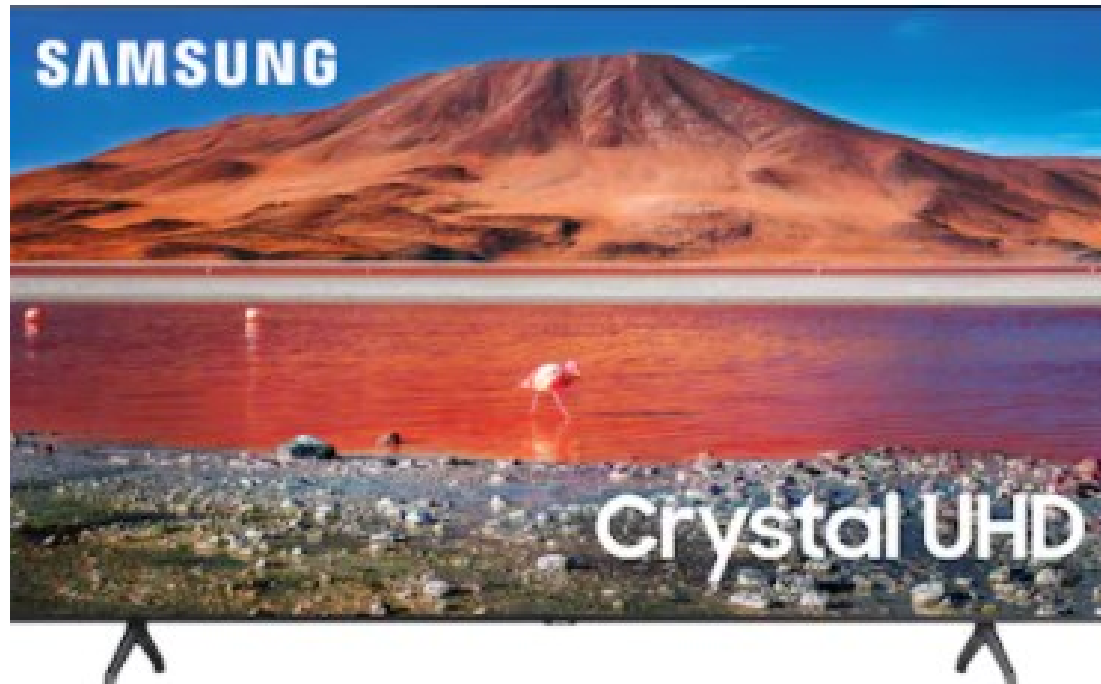


But: No 8K broadcast channels available in the US and none on the horizon at this time (Jan 2022) and little 8K media available !

Consider Television Sets and Monitors

4K UHD Television

Pixels: 3840 Horizontal and 2160 Vertical



Best Buy Jan 2022

Samsung - 43" Class 7 Series LED 4K UHD Smart Tizen TV

Model: UN43TU7000FXZA SKU: 6401740

★★★★★ (6,738)

Price Match Guarantee

\$329.99

Save \$70 Was \$399.99

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: $(3840 \times 2160) \times 120 \times (48) = 48 \text{ G bits/sec}$
(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: $192\text{K} \times 24 \times 2 = 9.2 \text{ Mbits/sec}$

- 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: $192K \cdot 24 \cdot 2 = 9.2$ Mbits/sec

Total bits: $48 \cdot 60 \cdot 120$ Gb = 346,000 Gb

Total bytes: $48 \cdot 60 \cdot 120 / 8$ 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: $192K \cdot 24 \cdot 2 = 9.2$ 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 price is \$55/month but it's worth noting that 5GB doesn't go a long way, so if you're planning on sharing a plan, make sure you're both only using it for browsing and checking emails. This plan includes access to the Verizon premium network, but no streaming service or cloud storage perks.

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



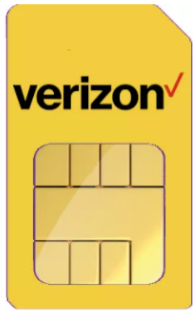
Verizon 10GB shared data: **from \$65 per month**

The second shared data plan is a 10GB option, which we'd recommend for most people who want to share their plan across multiple users or devices. Again, 10GB doesn't go that far, but it's a helpful amount for most non-streaming tasks. This plan includes full 5G access on the Verizon network, 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?



TEHRADAR 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: $43,000 \text{ GB}/14 = 3070 \text{ GB} = 3.1 \text{ TB}$

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)

8GB
\$70/mo

You like to stream video and are always online (great for small families, too).

Premium 4G LTE Data
Unlimited Talk & Text
Carryover Data
Safety Mode
Data Boost \$15/1 GB
Verizon Up Rewards

Plan cost per month, plus \$20/mo line access fee per smartphone purchased on device payment. Plus taxes & fees.

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