EE 330
Spring 2024

Integrated Electronics

Lecture Instructors:	Randy Geiger 2133 Coover rlgeiger@iastate.edu 294-7745
Course Web Site:	http://class.ece.iastate.edu/ee330/
Canvas:	Use primarily for turning in assignments and reports "Grades" generated by Canvas are unrelated to the course grading policy

Lecture: MWF 8:50 –9:40 Rm 1011 Coover

Lab:				
	Sec 1	Tues	8:00 - 10:50	TA:
	Sec 2	Tues	5:10 - 8:00	TA:
	Sec 3	Wed	3:20 - 6:10	TA:
	Sec 4	Thur	3:10 - 6:00	TA:

Labs start this week !
HW Assignment 1 has been posted land is due on Monday

Laboratory Instructors:

Emmanuel Darko	ntidarko@iastate.edu
Emmanuel Amankrah	eakwesi@iastate.edu

Instructor Access:

- Office Hours
  - Monday, Wednesday, Friday 11:00-11:50
  - By appointment at other times
- Email
  - rlgeiger@iastate.edu
  - Include **EE 330** in subject
- Class Zoom Link

https://iastate.zoom.us/j/98798424526?pwd=K0Y3aG5Zd3RicDVEL0lrdnEyUm1hZz09

Passcode: **527579**

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.

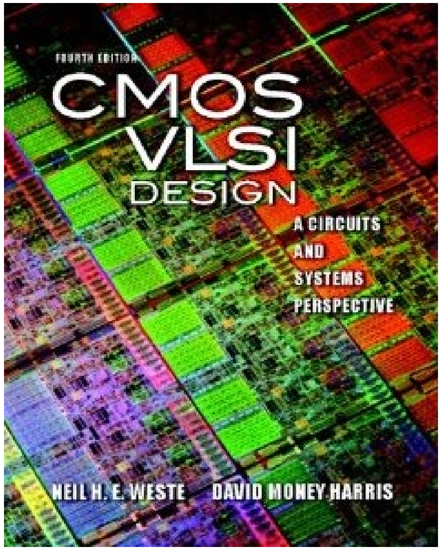
Grading Policy

3 Exams	100 pts each
1 Final	100 pts.
Attendance	100 pts. total
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

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

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 similar foruims or accessing these forums to see if anyone else has posted or solved problems. Specifically precluded is also any AI-generated content such as ChatGPT or similar tools.

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 <u>any</u> student that is caught using electronic forums such as Chegg (either posting or accessing) or ChatGPT for any part of this course.

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

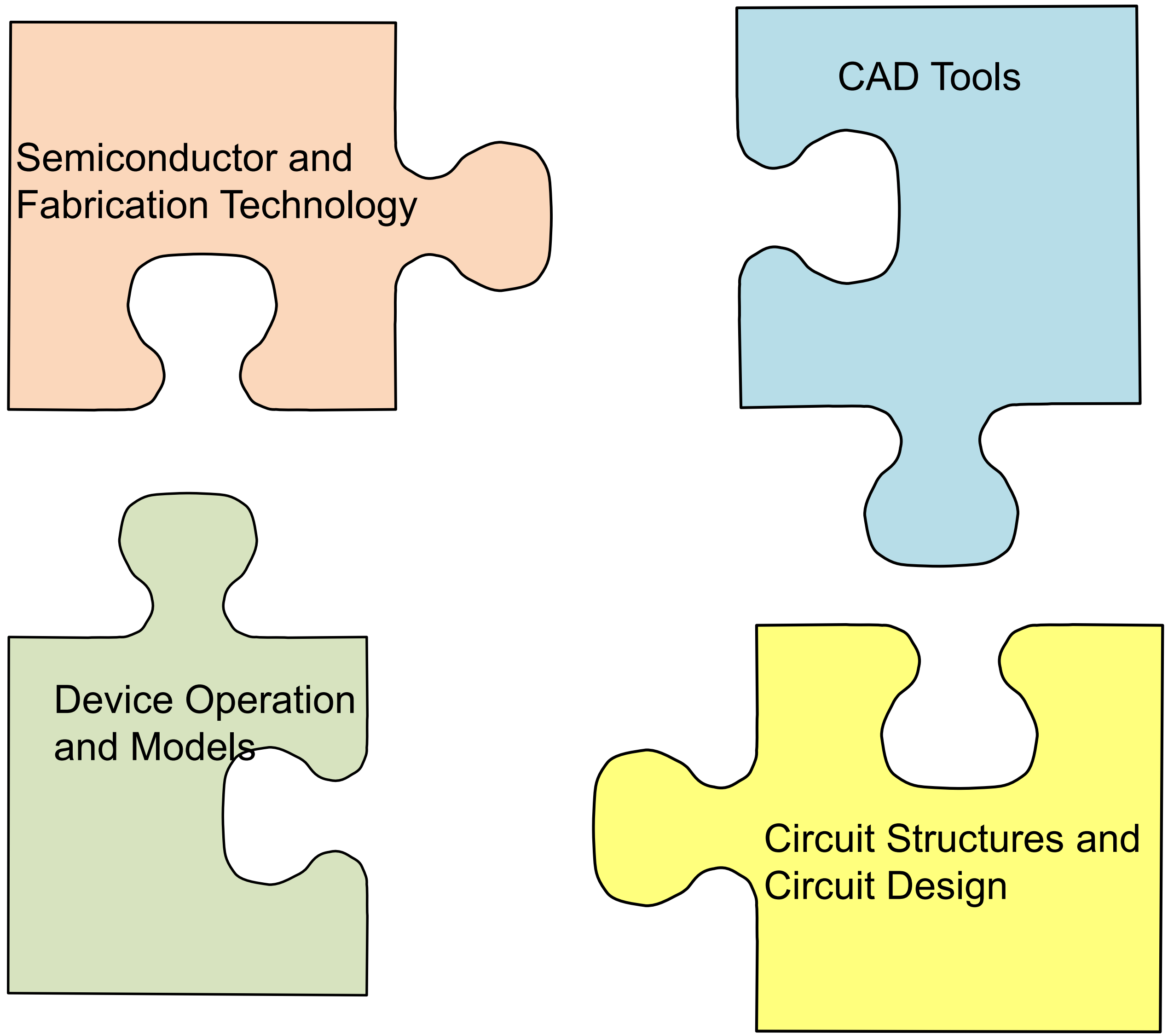
Participation in all class functions and provisions for special circumstances including special needs will be in accord with ISU policy

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.

Electronic Circuits in Industry Today

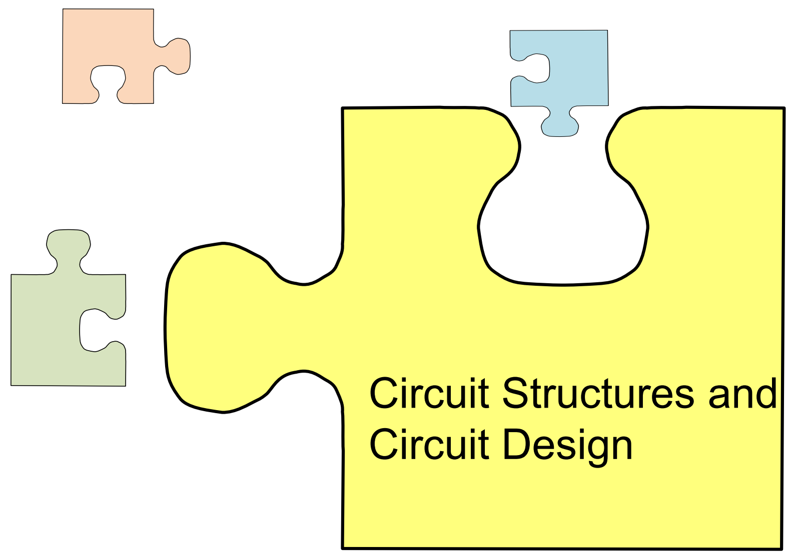
- Almost all electronic circuits are, at the most fundamental level, an interconnection of transistors and some passive components such as resistors, capacitors, and inductors
- For many years, electronic systems involved placing a large number of discrete transistors along with passive components on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

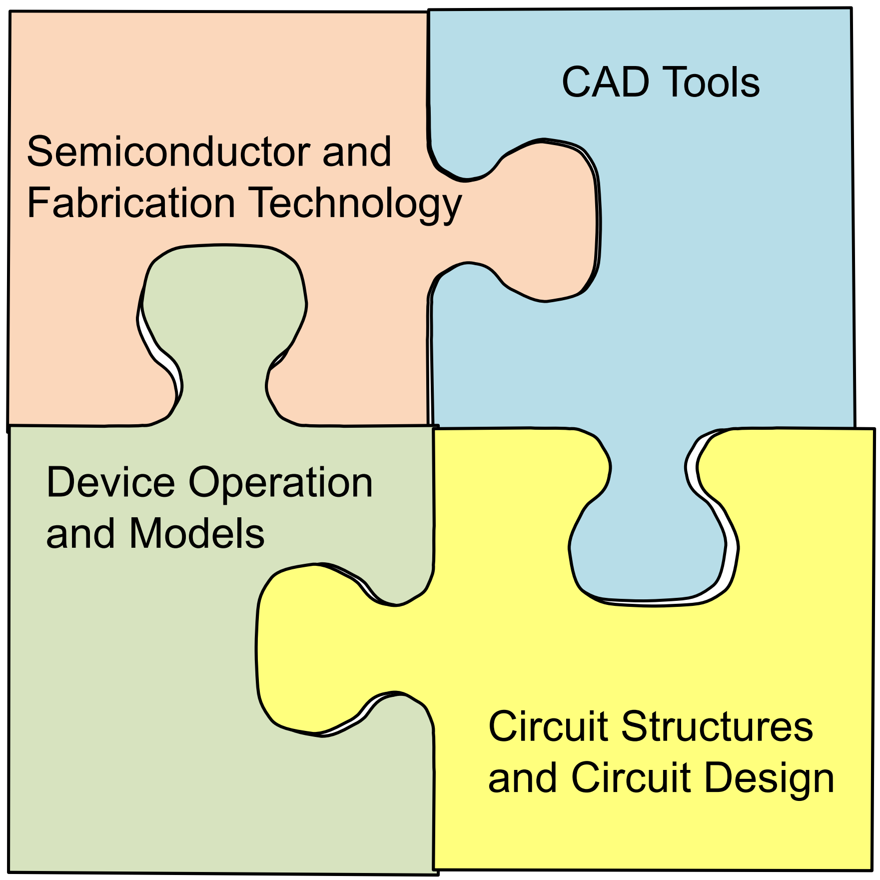
How Electronics was Approached for Decades



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

Laboratory Equipment

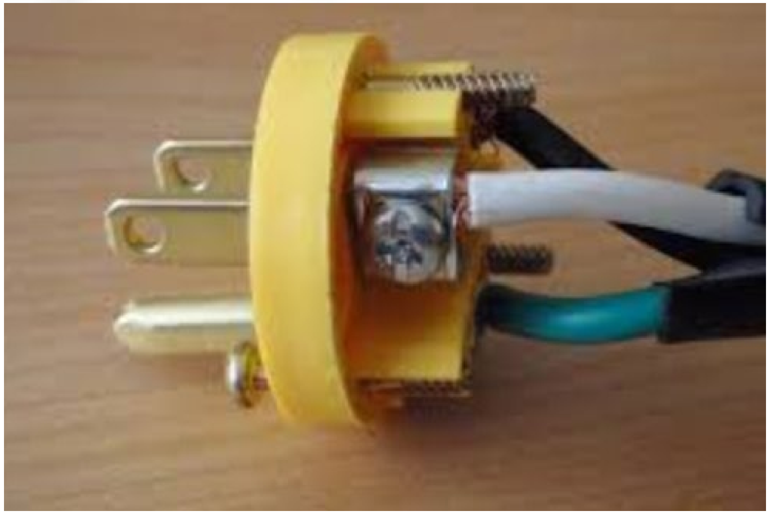
All laboratory equipment and all software used in the laboratory in this course are expected to be fully functional and operate correctly all of the time!

If for any reason it appears that there is an equipment malfunction or an error in software used in this course, bring it to the attention of your TA immediately. If for any reason the issue is not resolved by your TA, bring it to the attention of the course instructor.

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 10:00 am 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.

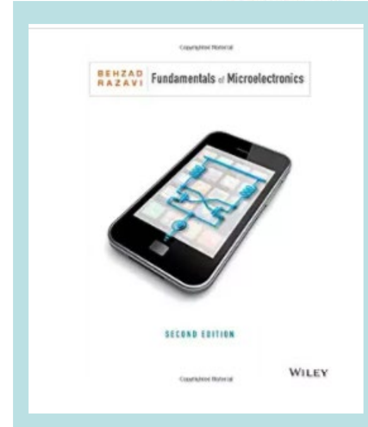
Laboratory reports are due at 11:59 p.m. on the day before the next laboratory experiment is scheduled. Reports will be turned in on Canvas. The last laboratory report will be due one week after the scheduled completion of the experiment.

Design Project

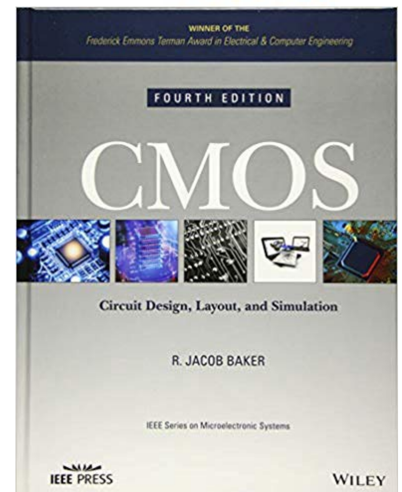
- Design project will focus on the design of an integrated circuit
- The final project will be culminated with an oral presentation and a written report

Reference Texts:

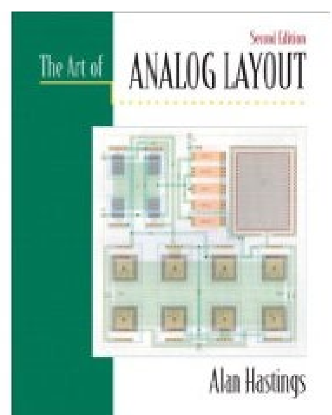
Fundamentals of Microelectronics
by B. Razavi, Wiley, 2013



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

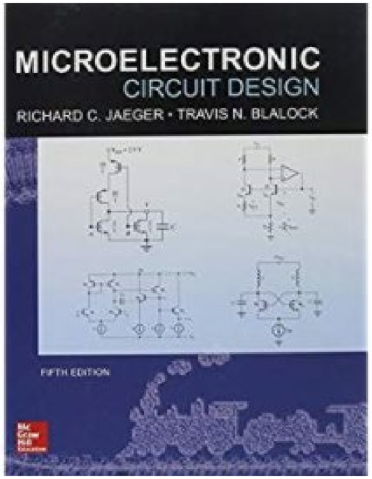


The Art of Analog Layout
by Alan Hastings, Prentice Hall, 2005

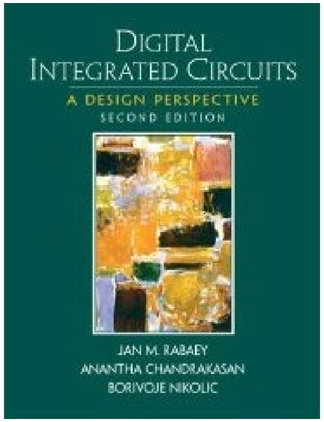


Reference Texts:

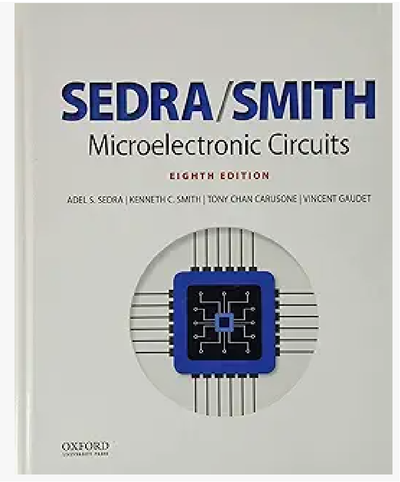
Microelectronic Circuit Design (4[th] edition)
By Richard Jaeger and Travis Blalock,
McGraw Hill, 2015



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

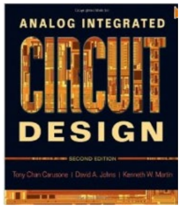


Microelectronic Circuits (8th Edition)
by Sedra and Smith, Oxford, 2019

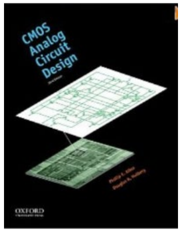


Other useful reference texts in the VLSI field:

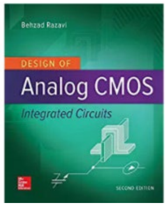
Analog Integrated Circuit Design (2nd edition)
by T. Carusone, D. Johns and K. Martin, Wiley, 2011



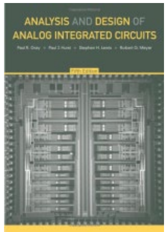
CMOS Analog Circuit Design (3rd edition)
by Allen and Holberg, Oxford, 2011.



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

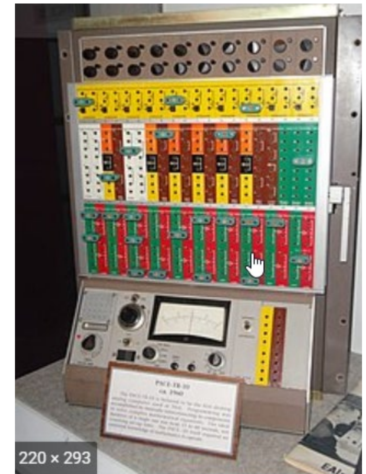
Obsolete or Current?

Technology Revolution

Obsolete or Current?

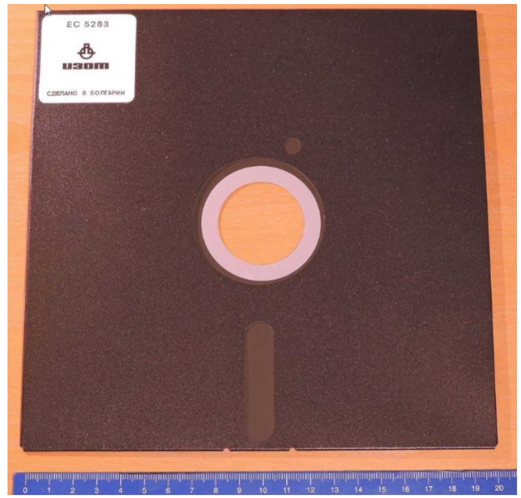
Technology Revolution

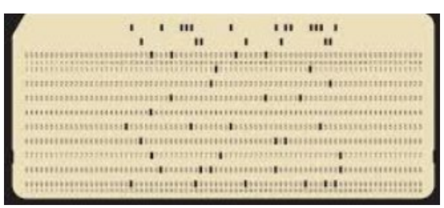
Obsolete or Current?



Technology Revolution

Obsolete or Current?





Technology Revolution

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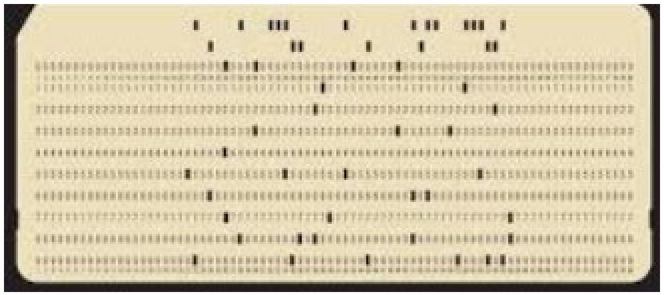

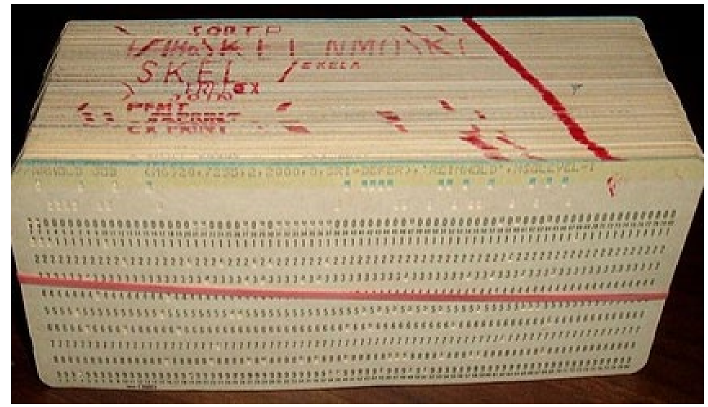

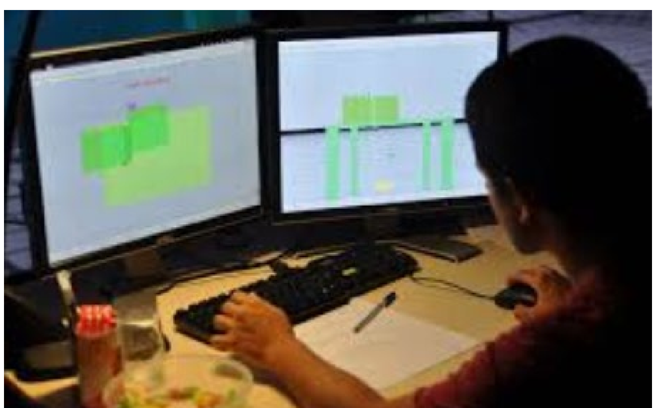

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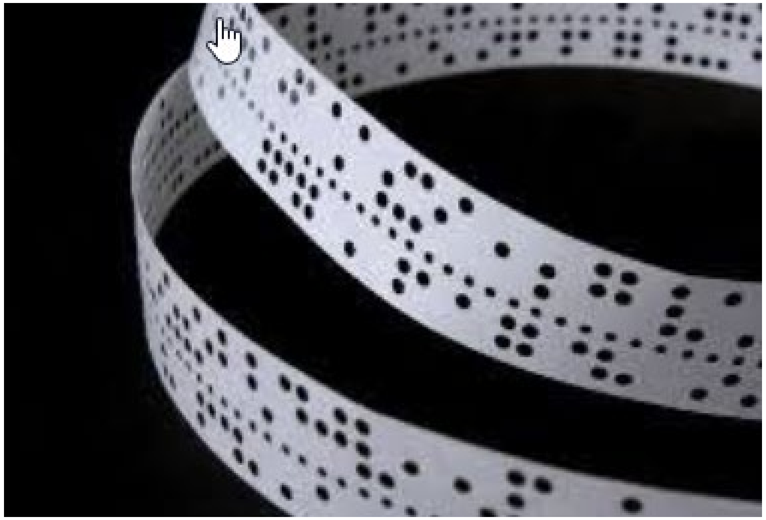

Technology Revolution

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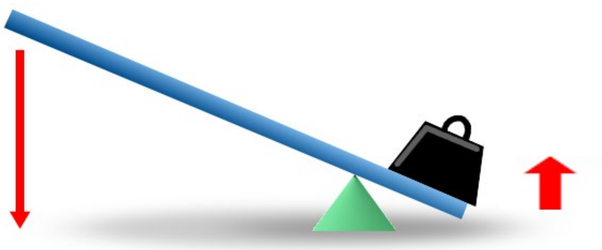

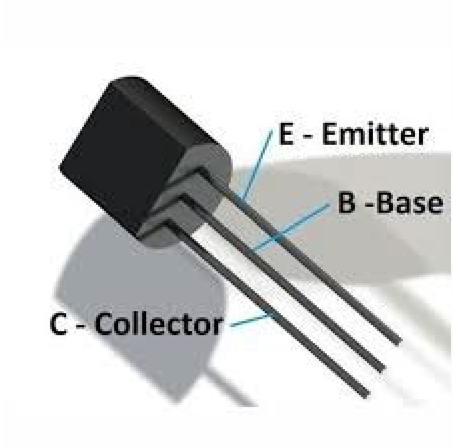

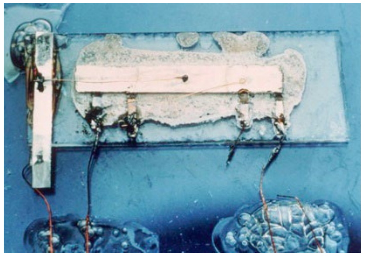

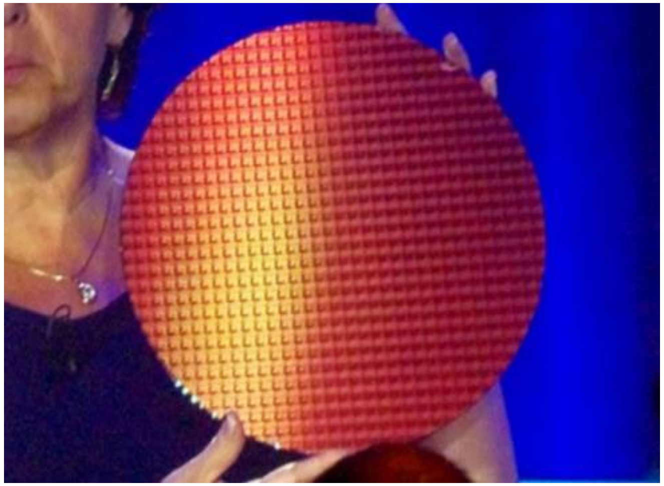

Technology Revolution

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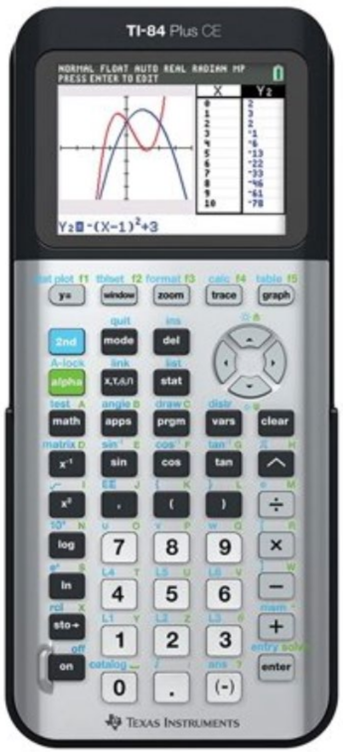


Graphing calculator

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 !

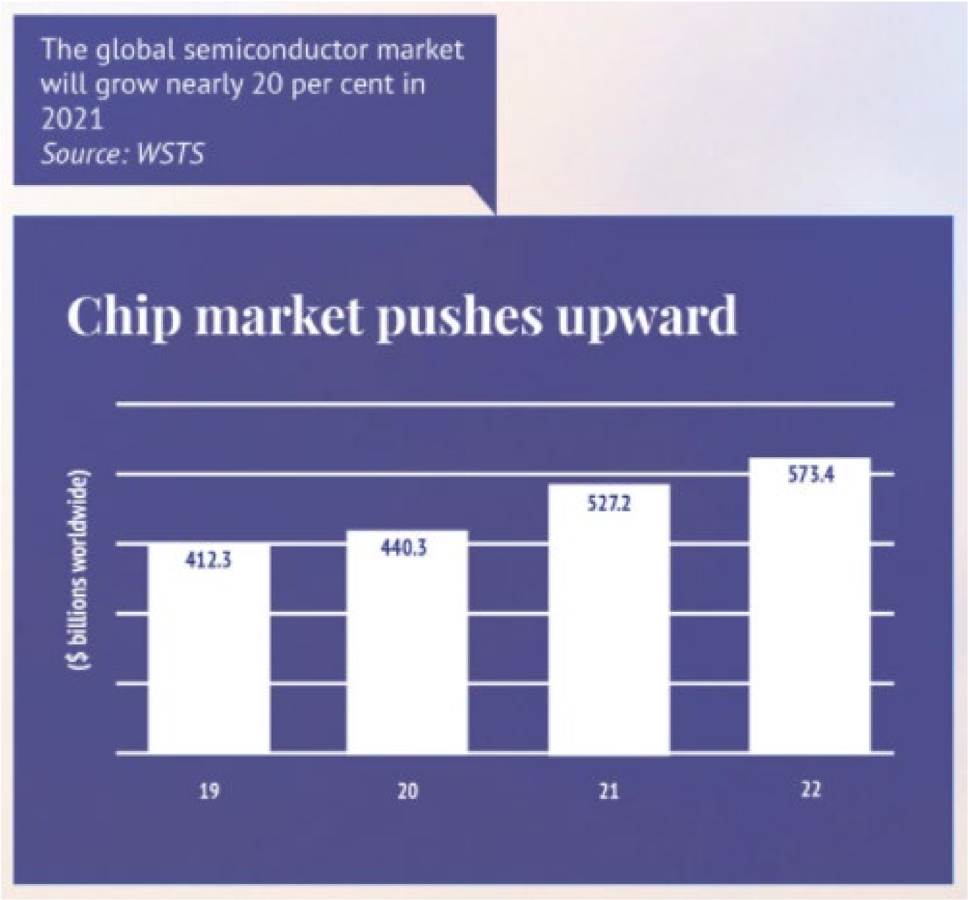
The Semiconductor Industry

(just the "chip" part of the business)

How big is it ?

How does it compare to other industries?

How big is the semiconductor industry?



How big is the semiconductor industry?

STAMFORD, Conn., December 4, 2023

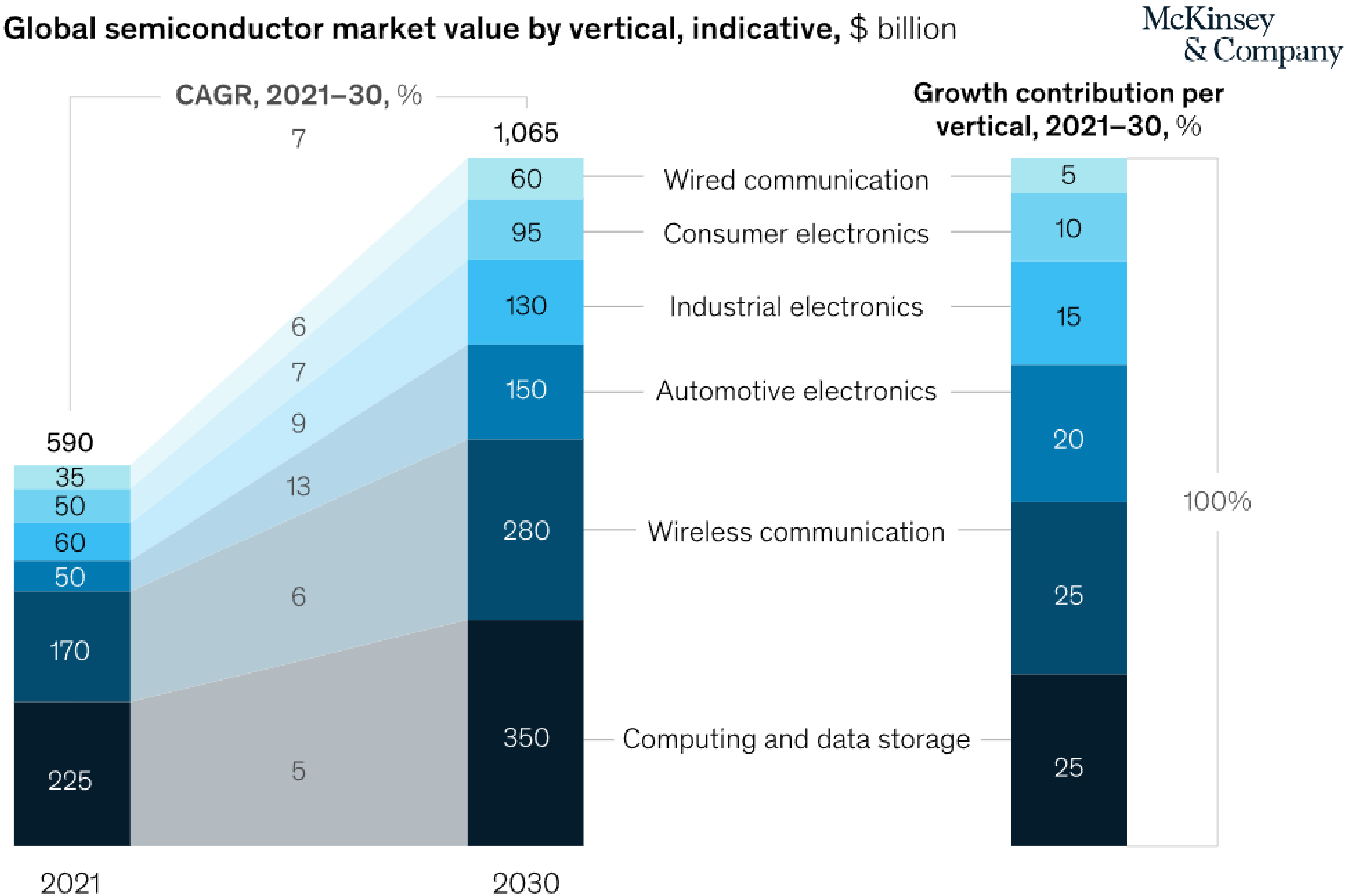
Gartner Forecasts Worldwide Semiconductor Revenue to Grow 17% in 2024

- ***Semiconductor Revenue to Total $624 Billion in 2024***
- ***Semiconductor Revenue to Decline 11% in 2023***
- ***Deployment of Workload Accelerators in Servers to Increase to More Than 20% by 2027***

Global semiconductor revenue is projected to grow 16.8% in 2024 to total $624 billion, according to the latest forecast from Gartner, Inc. In 2023, the market is forecast to decline 10.9% and reach $534 billion.

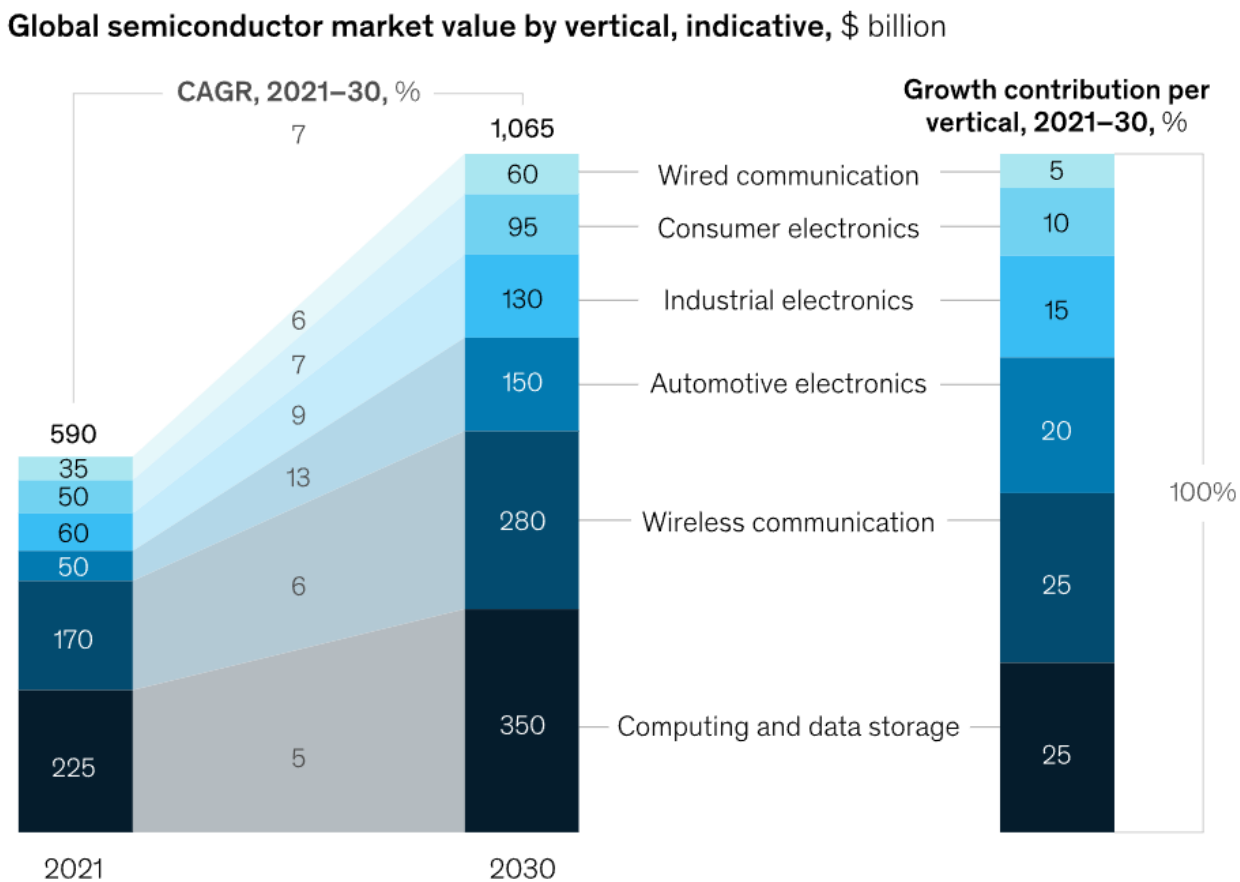
- Annual sales around $625B in 2024
- Somewhat rough in 2023
- 17% annual growth rate
- Unprecedented demand for engineers in the field

How big is the semiconductor industry?



https://www.mckinsey.com/industries/semiconductors/our-insights/the-semiconductor-decade-a-trillion-dollar-industry

What is driving the growth?



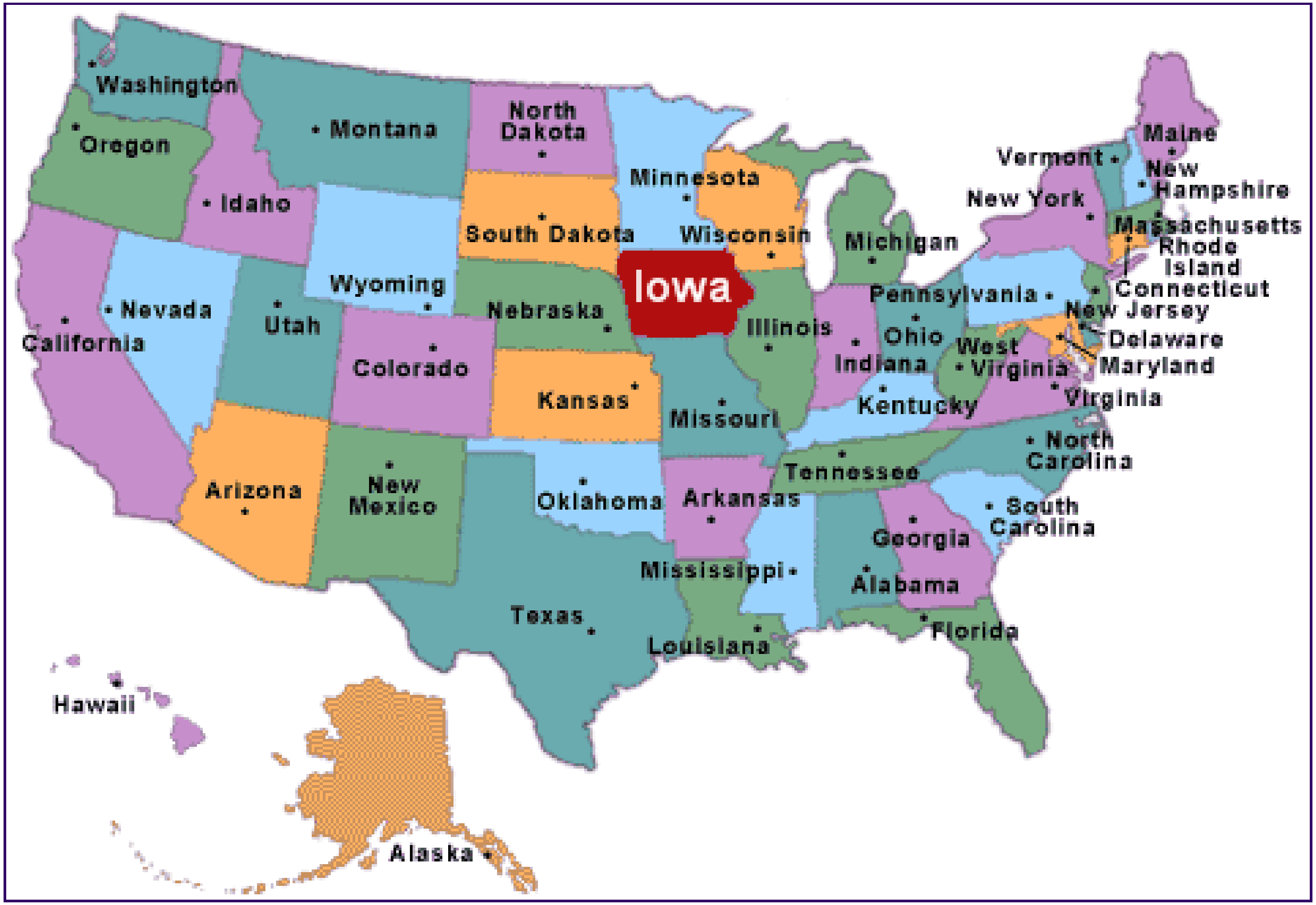
- Automotive
- Wireless Communications
- Computing and Data Storage

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
Second in Soybean production
First in Egg production
First in Hog production (nearly 3x 2^{nd} rank)
First in Red Meat production (2020)

Updated August 2023

Iowa-Centric Commodities

Corn

Beans

Iowa-Centric Commodities

Corn **Beans**

Agricultural Commodities are a Major Part of the Iowa Economy

Value of Agricultural Commodities

Corn Production

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

Soybean Production

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

LANDUS COOPERATIVE

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

Based upon Jan 16, 2024 markets in Boone Iowa

	Corn	Soybeans
Jan 2024 delivery	4.28	11.82

Value of Agricultural Commodities

(Based upon commodity prices in Boone Iowa on Aug 21, 2023)

(simplifying assumption: value constant around world)

Corn Production

	Bushels (Billions)	Value (Billion Dollars)
Iowa	**2.2**	**$9.4**
United States	**12**	**$51**
World	**23**	**$98**

Soybean Production

	Bushels (Millions)	Value (Billion Dollars)
Iowa	**340**	**$4.0**
United States	**3,100**	**$37**
World	**8,000**	**$95**

Projected world 2024 semiconductor sales of $625B about 310% 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 expected to exceed $1T/Year by 2030

How does it compare to Iowa-Centric Commodities?

Larger than major agricultural commodities (almost 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

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

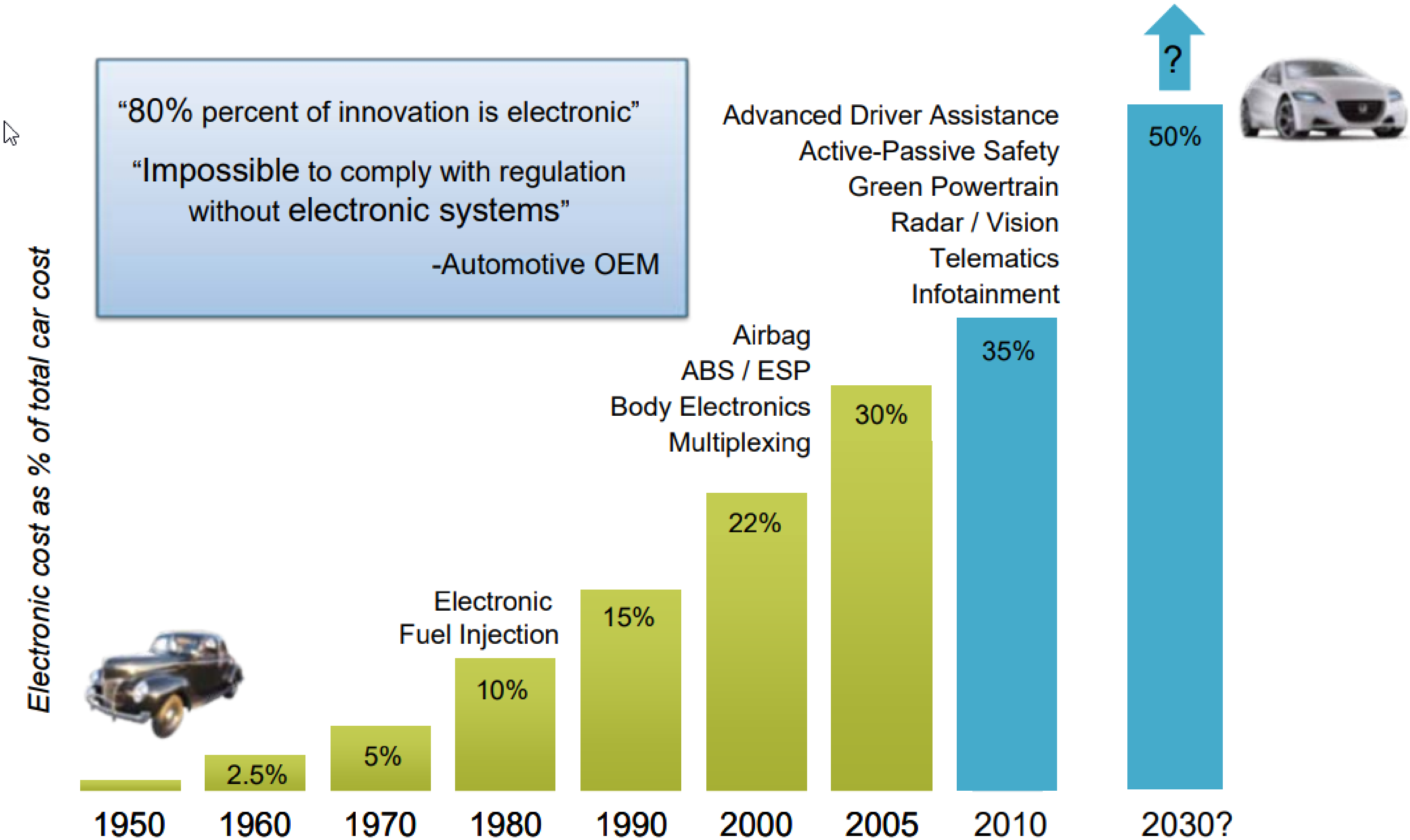
Is an automobile an electronics “gadget”?

Automotive Electronic Content Growth

"80% percent of innovation is electronic"

"Impossible to comply with regulation without electronic systems"

-Automotive OEM



Rewards in the Electronics Field

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

IEEE-USA

SALARY & BENEFITS SURVEY

2016 EDITION

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

	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
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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

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 (Aug 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*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)

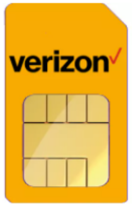
Resolution: 24 bits (16 bits or less usually adequate)

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 ??

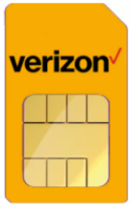
What does data really cost today (Aug 2021)?



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 w
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

How much would it cost to download a 2-hour 4K UHD TV "movie" using RAW audio and video on a Verizon Smart Phone today?

Assume Data Cost us $2/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: $86,000

- 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 (HDTV) instead of UHD

Video:

RAW (uncompressed) video data requirements: (1920*1080)*24*(32) = 1.59 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

- HDTV video streams used by the broadcast industry are typically between 14MB/sec and 19MB/sec (a compressive coding of about 14:1)
- But even with compression, the amount of data that must be processed and stored is very large
- Large electronic circuits required to gather, process, record, transmit, and receive data for HDTV

An example of electronic opportunities ?

Consider High Definition Television (HDTV) instead of UHD

Video:

RAW (uncompressed) video data requirements: (1920*1080)*24*(32) = 1.59 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

Cost for HDTV movie with compression @ $2/GB?

$$\text{Bytes} = 14\frac{\text{MB}}{\text{sec}} \text{x} 60 \frac{\text{sec}}{\text{min}} \text{x} 120 \text{min} = 101 \text{ GB}$$

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