Lecture 1
Introduction to Advanced Digital Logic Design

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ECE 303

Advanced Digital Design

Outline

- Class administration
- Introduction through a simple digital design example

Class Administration

- Canvas
  - Documents
    - PDF of Slides
    - Homework/lab assignments and solutions
    - Reading material
    - Other relevant documents
  - Announcements
- Email me or TA your questions and feedback to the class

Class Prerequisites

- Basic understanding
  - Digital systems
  - Boolean logic operation and digital gates
  - Combinational and sequential logic
  - basics of electrical circuits
- Remind yourself on early chapters covered in 203

Related Cources

- Class will form a background for other classes in Computer Engineering
  - ECE 355: ASIC and FPGA Design
  - ECE 357: Introduction to VLSI CAD
  - ECE 459: VLSI Algorithmics
  - ECE 361: Computer Architecture
  - ECE 391: CMOS VLSI Design
  - ECE 392: VLSI Design Projects
  - ECE 393/493: Advanced Low Power Digital and Mixed-signal Integrated Circuits Design

Slides and Textbooks

- Slides:
  - This is the most important material
  - All material needed for homework/exam will be from slides
- Textbook: Digital Design Principles and Practices 5th Edition (John F. Wakerly)
  - Supplemental material to read
    - Slides will list related textbook chapters for you to read
    - Provide more descriptions/explanation
    - Not mandatory unless noted from the class
    - Lots of good examples of Verilog coding
  - Occasionally, I will refer you to learn textbooks

Lab

- Lab will be assigned for you to practice commercial design tools from Cadence
  - Genus for synthesis
  - Xcelium for RTL simulation
- Lab requires access to Wilkinson lab
  - Support remote access from off-campus
  - Linux operating system
    - You need to learn some basic commands
  - Instruction will be sent later

ASIC Design Sequence Class

Entry

Profession

ECE 303
Digital Design

- Digital Logic Design
- Logic Synthesis
- Technology Mapping
- Verilog/VHDL
- Finite State Machines

ECE 391
VLSI Design

- Chip Technology
- Transistor Theory
- CMOS Circuit Design
- Complex IC Design
- Custom IC Design

ECE 393
Advanced VLSI Design

- Special Advanced Topics
- Ultra-low Power IC Design
- Biomedical IC Design
- Machine Learning Accelerators
- Analog Mixed-signal IC Design

Grading Policy

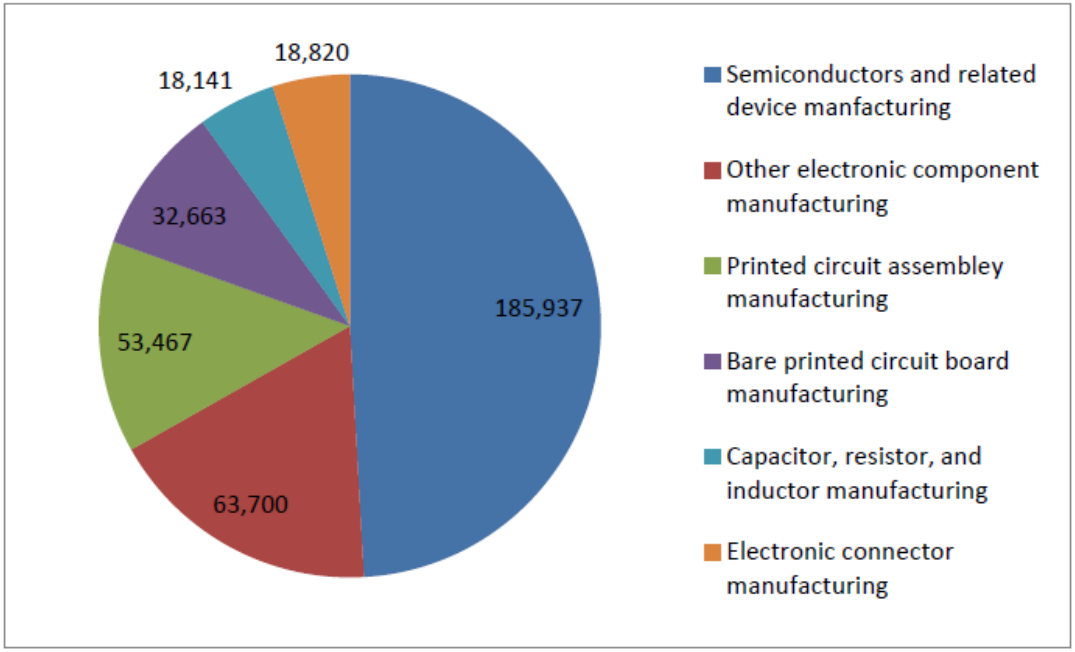
- Grades:
  - 40% Homework
  - 30% Midterm
  - 30% Final
- Late Penalty:
  - Credit will be deducted for late submission within 24 hours
  - No credit if you submit after solutions are posted
- Homework submission:
  - Electronically (through Canvas)

What is this all about?

- This course is about understanding the basic principles of building digital circuits that underlie all computing systems

Semiconductor Jobs

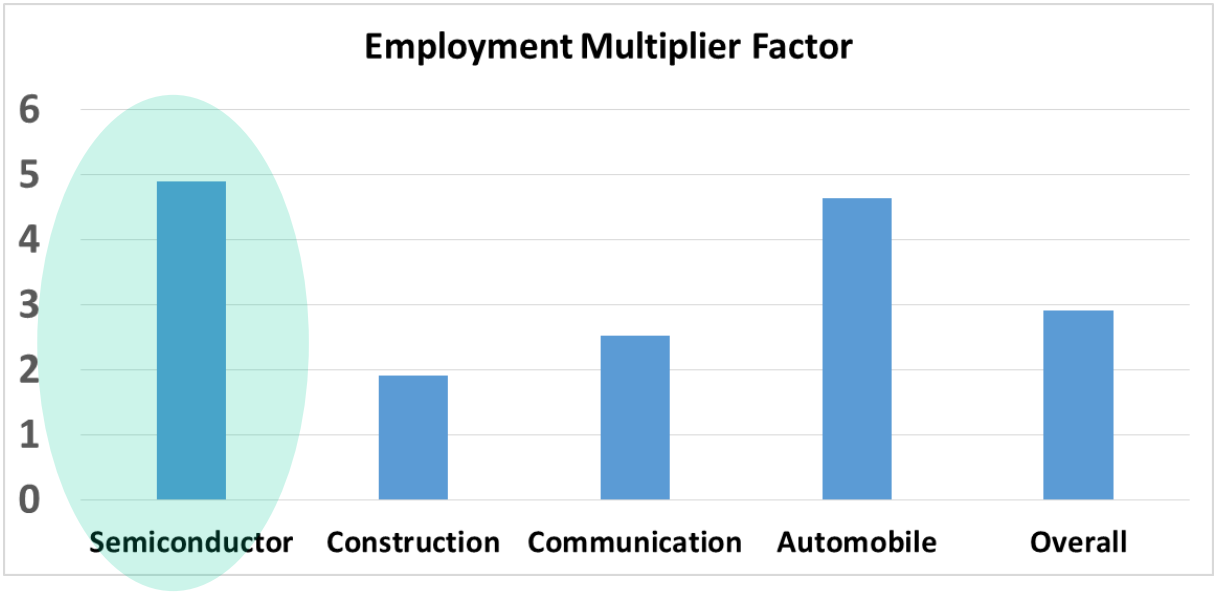
Figure 1: Employment in the U.S. Electronic Component Industry, by Subgroups, 2013



Source: BLS, 2015.

- Semiconductor: largest job sector in electronics industry

Semiconductor: Backbone of Electronics



- Employ 250,000 people in US; Supports >1 million jobs
- Multiplier factor of semiconductor jobs:
  - 4.9 jobs created from one semiconductor position
- 100X leveraging factor in revenue: >$10 trillion business
  - It is the size of oil industry!

Semiconductor Companies

Semiconductor Companies with >$10 Billion in Sales in 2021F

2021F Rank	2020 Rank	Company	Headquarters	2020 Total IC	2020 Total O-S-D	2020 Total Semi	2021F Total IC	2021F Total O-S-D	2021F Total Semi	2021/2020 % Change
1	2	Samsung	South Korea	58,555	3,298	61,853	78,850	4,235	83,085	34%
2	1	Intel	U.S.	76,328	0	76,328	75,550	0	75,550	-1%
3	3	TSMC (1)	Taiwan	45,572	0	45,572	56,633	0	56,633	24%
4	4	SK Hynix	South Korea	26,094	981	27,075	35,628	1,639	37,267	38%
5	5	Micron	U.S.	22,542	0	22,542	30,087	0	30,087	33%
6	6	Qualcomm (2)	U.S.	19,357	0	19,357	29,136	0	29,136	51%
7	8	Nvidia (2)	U.S.	14,659	0	14,659	23,026	0	23,026	57%
8	7	Broadcom Inc. (2)	U.S.	15,941	1,803	17,744	18,864	2,099	20,963	18%
9	12	MediaTek (2)	Taiwan	10,985	0	10,985	17,551	0	17,551	60%
10	9	TI	U.S.	12,731	843	13,574	15,889	1,015	16,904	25%
11	15	AMD (2)	U.S.	9,763	0	9,763	16,108	0	16,108	65%
12	11	Infineon	Europe	7,542	3,683	11,225	9,113	4,503	13,616	21%
13	10	Apple* (2)	U.S.	11,440	0	11,440	13,430	0	13,430	17%
14	14	ST	Europe	6,804	3,374	10,178	8,400	4,174	12,574	24%
15	13	Kioxia	Japan	10,553	0	10,553	12,132	0	12,132	15%
16	17	NXP	Europe	7,582	809	8,391	9,711	1,004	10,715	28%
17	19	Analog Devices (3)	U.S.	7,722	405	8,127	9,575	504	10,079	24%
—	—	Top-25 Total		364,170	15,196	379,366	459,683	19,173	478,856	26%

(1) Foundry (2) Fabless (3) Includes aquired company's sales in 2020 and 2021 results.

Source: Company reports, IC Insights *Custom devices for internal use.

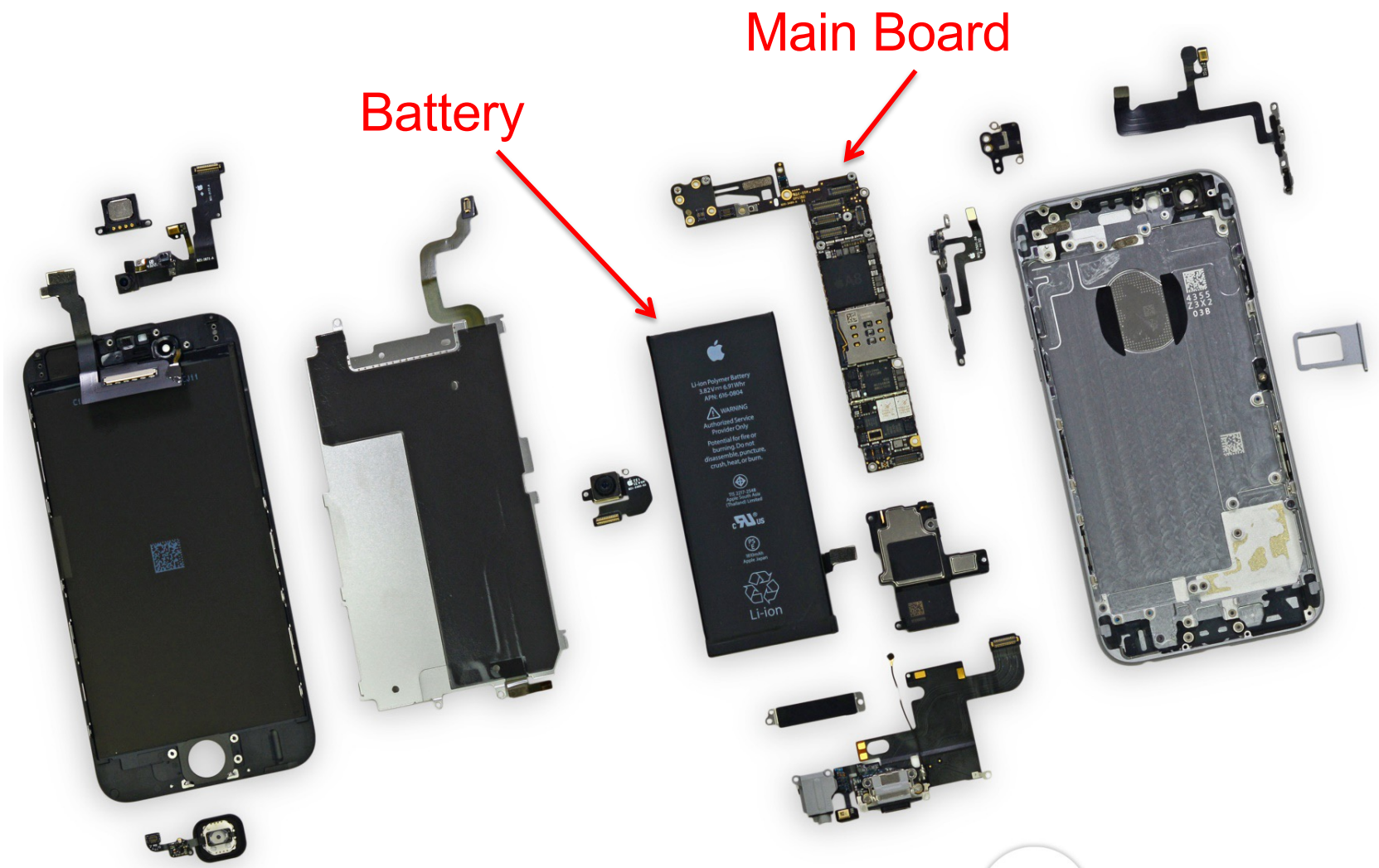
Below are some IC design companies

- Intel, IBM, Texas Instruments, Qualcomm, Broadcom, AMD, Apple, Samsung, Maxim, NXP, Nvidia, Xilinx, Microchip, Cirrus Logic, ON Semiconductor, Skyworks, STM, ARM, Analog Device, Micron, Silicon Labs, Marvel, Rambus, Omnivision, Cypress, Infineon, Maxlinear, etc.
- Software/System companies who also design ICs:
  - Google, Facebook, Amazon, Microsoft, Alibaba, etc;

Case Study of Iphone 6

ifixit.com

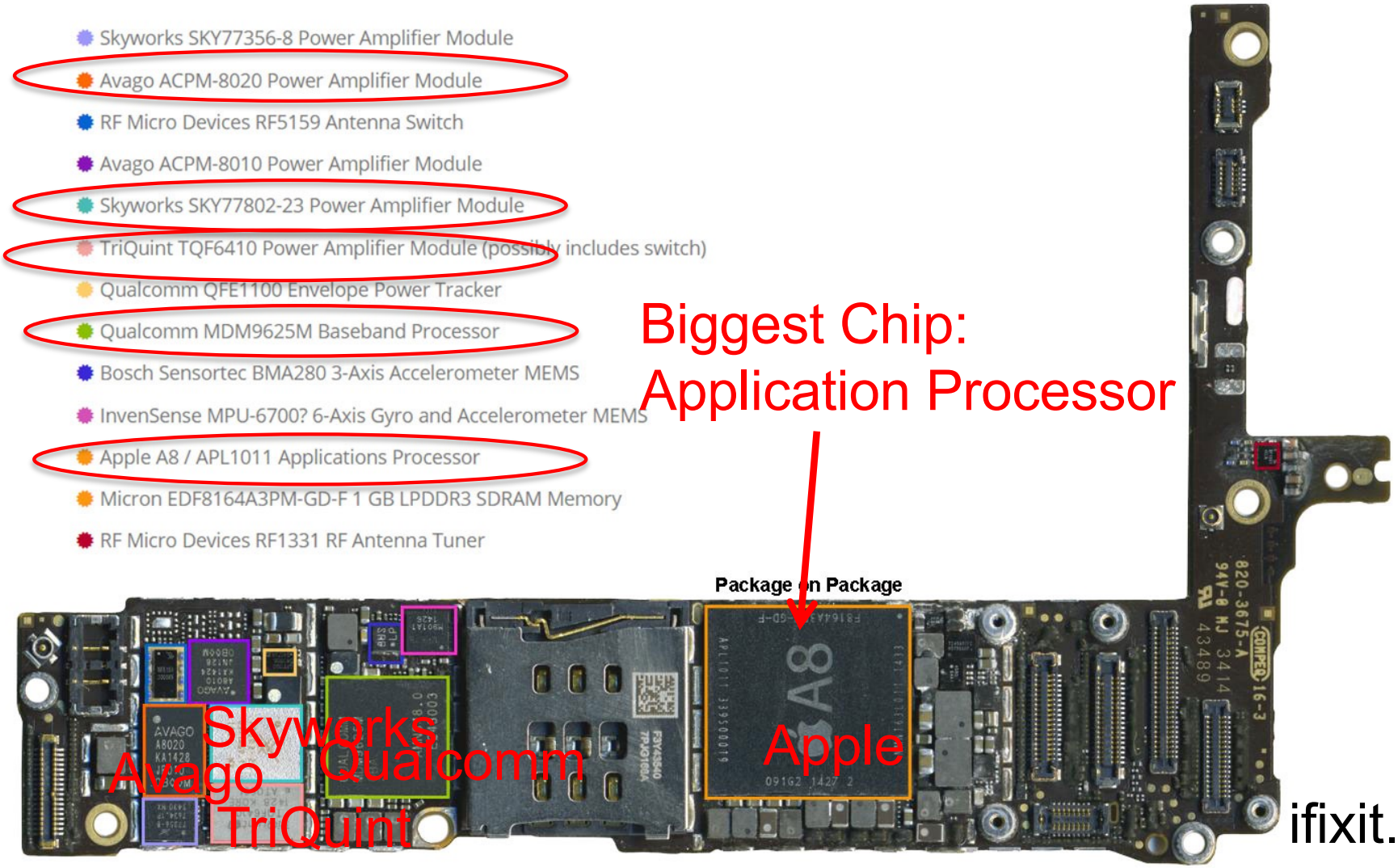
Case Study of Iphone 6



Iphone 6 (Front Board)

- Skyworks SKY77356-8 Power Amplifier Module
- Avago ACPM-8020 Power Amplifier Module
- RF Micro Devices RF5159 Antenna Switch
- Avago ACPM-8010 Power Amplifier Module
- Skyworks SKY77802-23 Power Amplifier Module
- TriQuint TQF6410 Power Amplifier Module (possibly includes switch)
- Qualcomm QFE1100 Envelope Power Tracker
- Qualcomm MDM9625M Baseband Processor
- Bosch Sensortec BMA280 3-Axis Accelerometer MEMS
- InvenSense MPU-6700? 6-Axis Gyro and Accelerometer MEMS
- Apple A8 / APL1011 Applications Processor
- Micron EDF8164A3PM-GD-F 1 GB LPDDR3 SDRAM Memory
- RF Micro Devices RF1331 RF Antenna Tuner

Biggest Chip:
Application Processor



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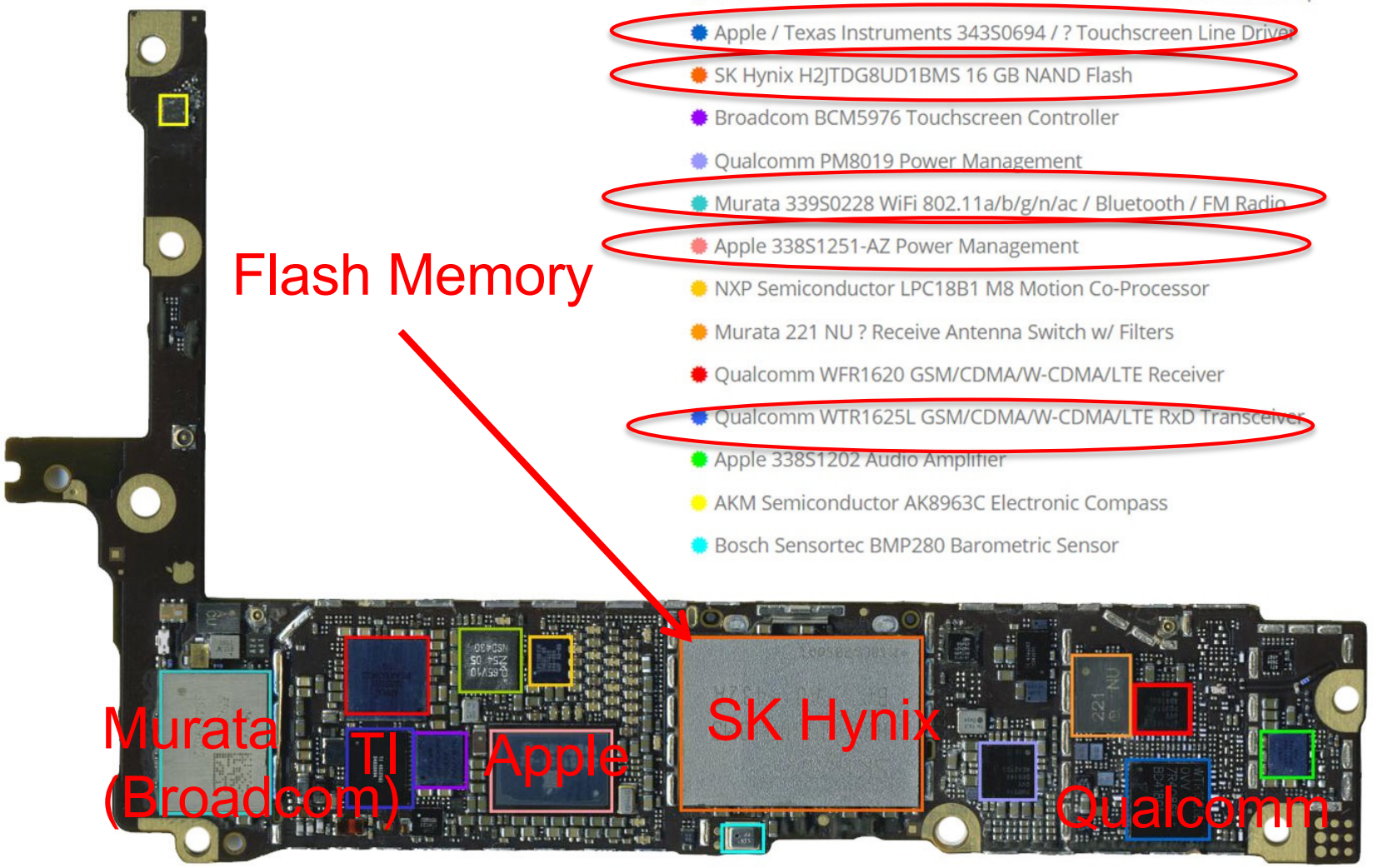
Iphone 6 (Back Board)

- NXP Semiconductor PN548 NFC Controller w/ Secure Element Chip
- Apple / Texas Instruments 343S0694 / ? Touchscreen Line Driver
- SK Hynix H2JTDG8UD1BMS 16 GB NAND Flash
- Broadcom BCM5976 Touchscreen Controller
- Qualcomm PM8019 Power Management
- Murata 339S0228 WiFi 802.11a/b/g/n/ac / Bluetooth / FM Radio
- Apple 338S1251-AZ Power Management
- NXP Semiconductor LPC18B1 M8 Motion Co-Processor
- Murata 221 NU ? Receive Antenna Switch w/ Filters
- Qualcomm WFR1620 GSM/CDMA/W-CDMA/LTE Receiver
- Qualcomm WTR1625L GSM/CDMA/W-CDMA/LTE RxD Transceiver
- Apple 338S1202 Audio Amplifier
- AKM Semiconductor AK8963C Electronic Compass
- Bosch Sensortec BMP280 Barometric Sensor



Iphone 6 Bill of Material (BOM)

Preliminary Apple iPhone 6 & 6 Plus Teardown Estimates

	Apple		Apple		Apple	
	iPhone 5S - Analysis Oct 2013		iPhone 6 (Sprint Version)		iPhone 6 Plus (Sprint Version)	
Components / Hardware Elements						
Retail Price		**$649.00**		**$649.00**		**$749.00**
Total BOM Cost		**$190.85**		**$196.10**		**$211.10**
Manufacturing Cost		$4.00		$4.00		$4.50
BOM + Manufacturing		**$194.85**		**$200.10**		**$215.60**
Major Cost Drivers						
Memory						
NAND Flash + DRAM	16GB NAND + 1GB LPDDR3	$18.30	16GB NAND + 1GB LPDDR3	$15.00	16GB NAND + 1GB LPDDR3	$15.00
Display & Touch-screen	**4" Retina Display w/ Touch**	$41.00	**4.7" 1334x750 IPS LCD, w/ In-Cell Touch**	$45.00	**5.5" 1920x1080 IPS LCD, w/ In-Cell Touch**	$52.50
Processor - AP	**Apple 64-bit A7 Processor**	$17.00	**Apple 64-bit A8 Processor**	$20.00	**Apple 64-bit A8 Processor**	$20.00
Camera(s)	**8MP / 1.2MP**	$14.80	**8MP w/'Focus Pixels' / 1.2MP**	$11.00	**8MP w/ 'Focus Pixels' and OIS / 1.2MP**	$12.50
Wireless Section - BB/RF/PA	**Qualcomm MDM9615M+WTR1605L+Front End**	$28.50	**Contains Qualcomm MDM9625M + WTR1625L + WFR1620 + Front End**	$33.00	**Contains Qualcomm MDM9625M + WTR1625L + WFR1620 + Front End**	$33.00
User Interface & Sensors	**Includes fingerprint sensor assembly**	$22.00	**Contains Audio Codec, NFC Controller, & Sensors**	$22.00	**Contains Audio Codec, NFC Controller, & Sensors**	$22.00
BT / WLAN	**Contains Broadcom BCM4334**	$4.50	**Contains Broadcom BCM4345**	$4.50	**Contains Broadcom BCM4345**	$4.50
Power Management	**Dialog + Qualcomm**	$6.25	**Dialog + Qualcomm**	$7.00	**Dialog + Qualcomm**	$7.00
Battery	**3.8V, 1560mAh Li-Polymer**	$3.50	**3.8V, 1810mAh Li-Polymer**	$3.60	**3.8V, 2915mAh Li-Polymer**	$4.60
Mechanical / Electro-Mechanical		$30.00		$30.00		$35.00
Box Contents		$5.00		$5.00		$5.00

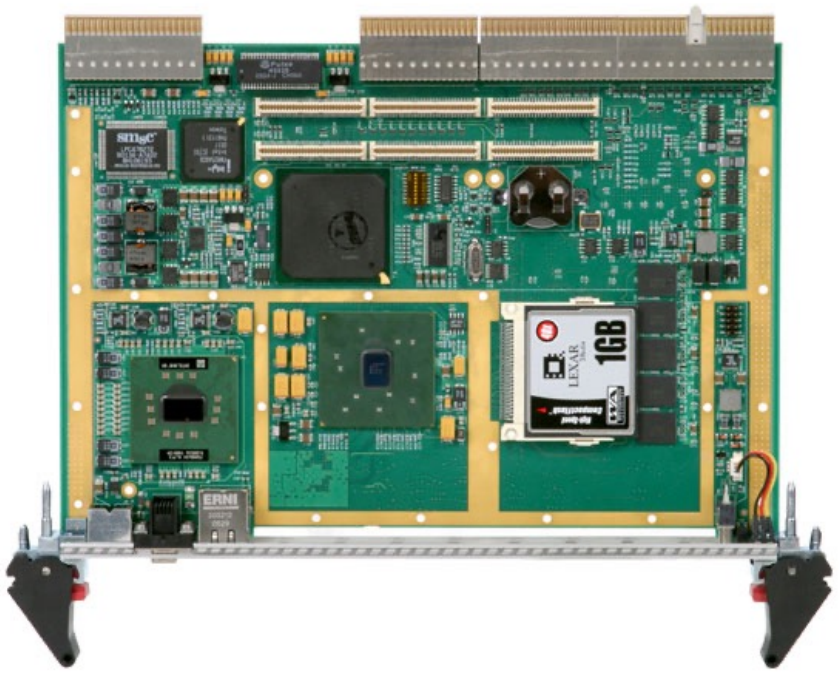
9/23/2014

#4 Memory
#1 Display
#2 App proc.
#5 Camera
#3 RF

- Chip price is proportional to silicon area; Integration is key in semiconductor

Inside Computer System

- A computer system may in fact contain several components
- CPU Chip (Our focus)
- Memory Chip
- Power Supply
- Motherboard
- Hard Drive
- Keyboard/Mouse

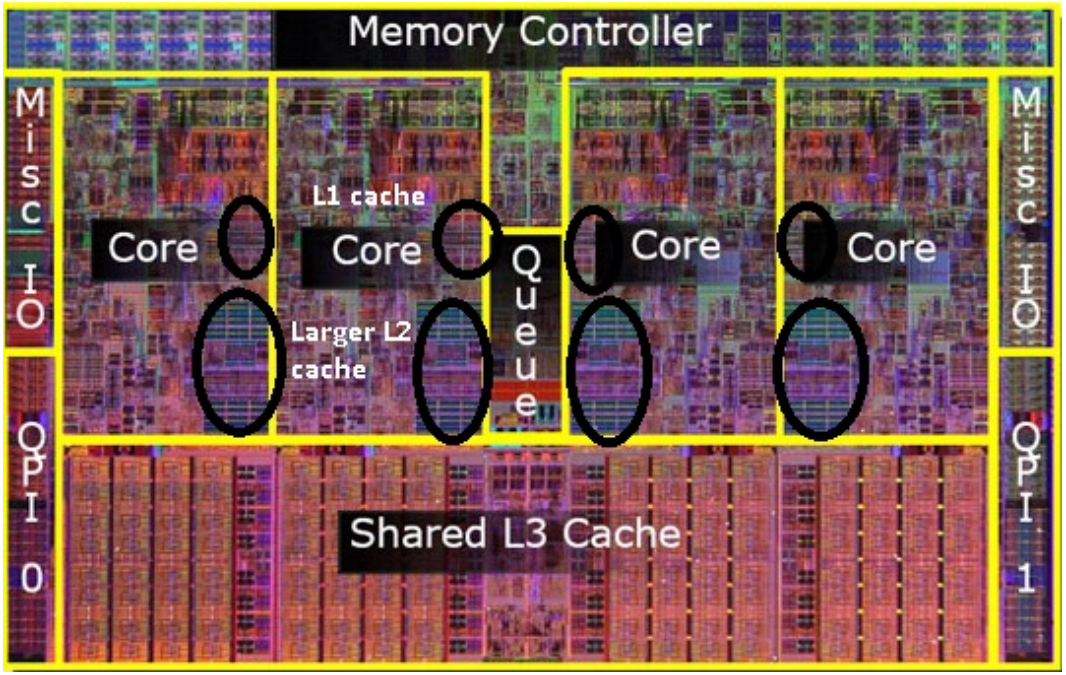


Inside A CPU Chip

Datapath : where computation happens (adding values, comparing values, multiply, divide, …

Memory: maintain data (values used during computation) and executable (instructions of the program code)

Interconnect/IO: to bring all components together and communicate with outside world



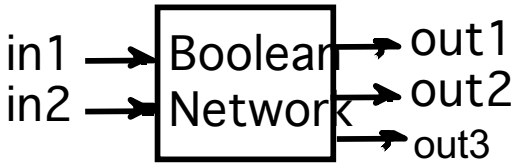
- Intel Core i5 750 2.66GHz Processor
- Quad Core
- 32kB L1 Cache per core
- 256dB L2 Cache per core
- 8MB L3 Cache shared

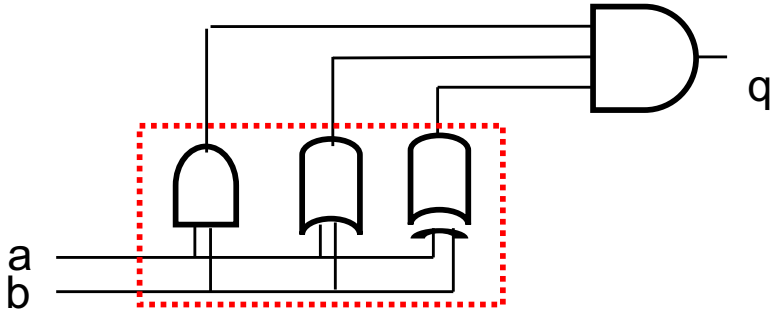
Inside A CPU Chip

- Datapath:
  - Arithmetic computation
    - Need to have adders, multipliers, comparators, multiplexers, etc.
- Memory
  - Need storage elements
    - Latches, flip flops, SRAM …
- Interconnect/IO
  - High speed communication with external devices or internal modules

Digital Hardware Systems

TWO MAIN FAMILIES: Combinational vs. Sequential Logic

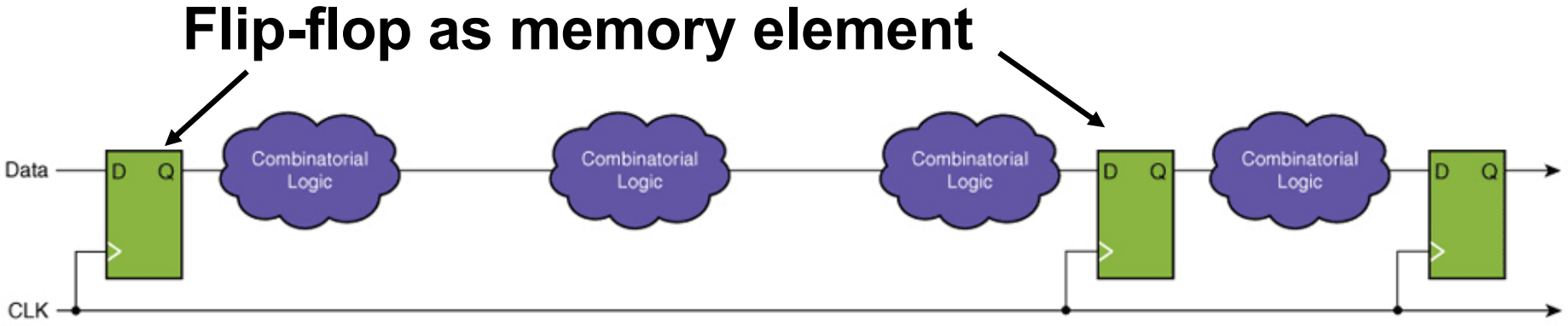




Combinational logic

- **Outputs are a pure function of the inputs ;**
- **Memory-less (output does not depend on past state) ;**
- **Computation starts as soon as inputs are available/change (asynchronous behavior);**

Digital Hardware Systems



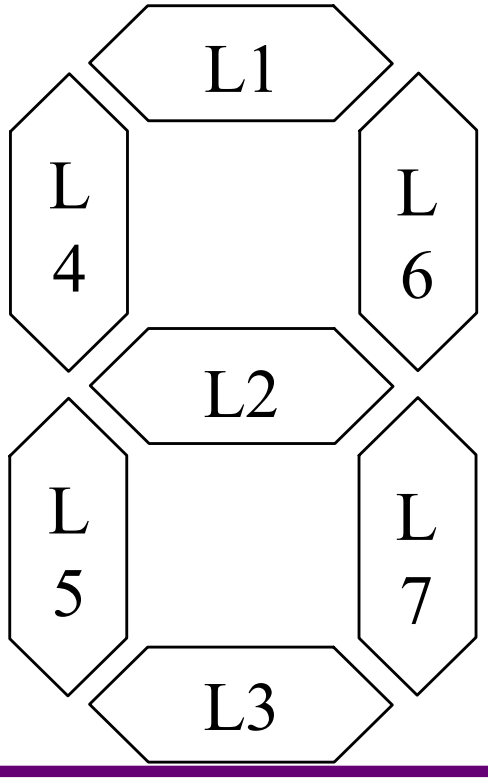
Sequential logic

- **Outputs are a function of the state held in memory elements and inputs;**
- **Memory elements needed to hold past values and provide as inputs to the next cycle;**
- **Operation is triggered by a clock signal;**

Case Study of a Simple Logic Design

- Chip to drive digital display
- Given four bit input
- Display decimal digit between 0 and 9

Output:
LED Illumination

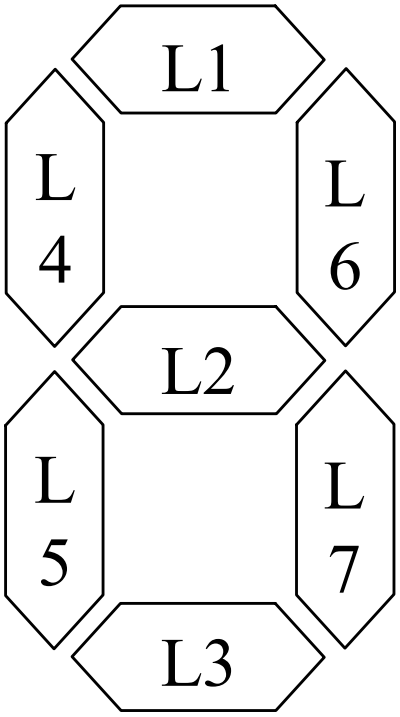


Binary coded decimal (BCD)

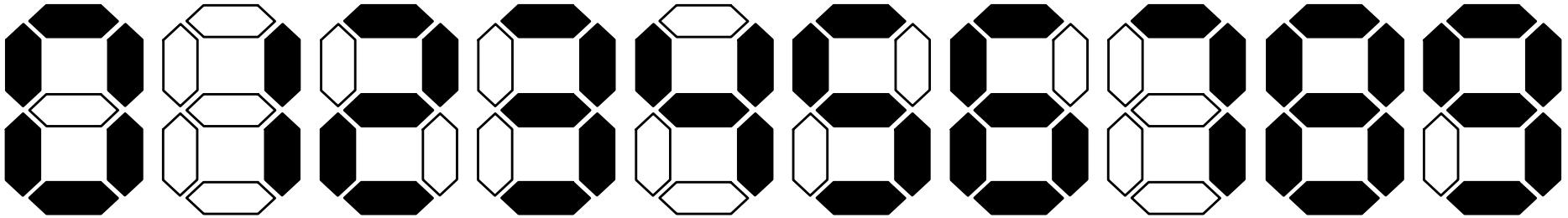
4 bits Input

B3	B2	B1	B0	Val
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9

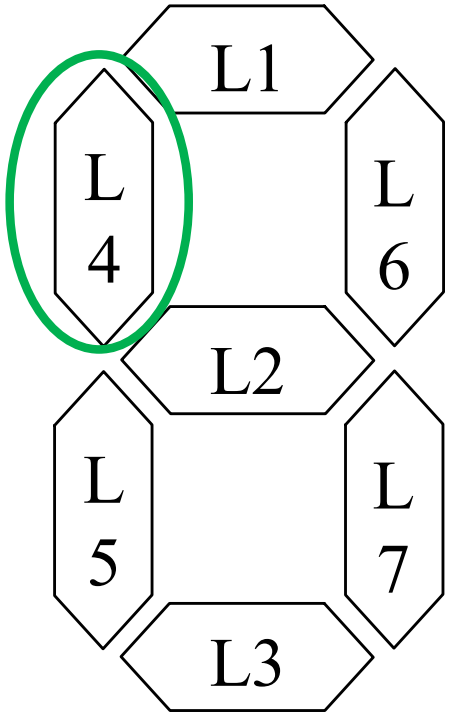
Case Study (cont.)



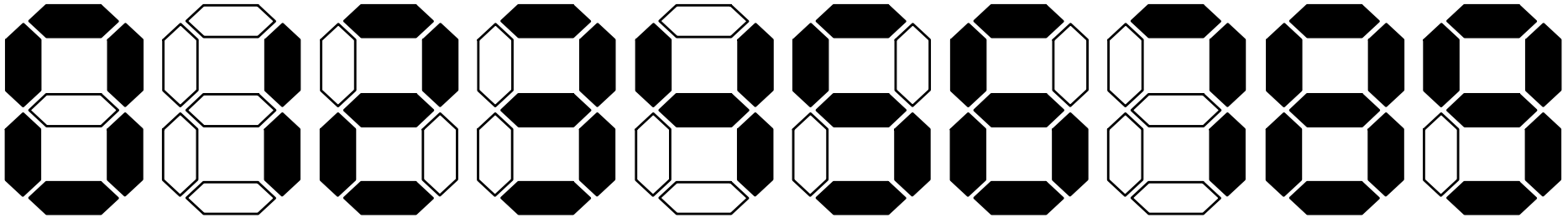
B3	B2	B1	B0	Val	L1	L2	L3	L4	L5	L6	L7
0	0	0	0	0	1	0	1	1	1	1	1
0	0	0	1	1	0	0	0	0	0	1	1
0	0	1	0	2	1	1	1	0	1	1	0
0	0	1	1	3	1	1	1	0	0	1	1
0	1	0	0	4	0	1	0	1	0	1	1
0	1	0	1	5	1	1	1	1	0	0	1
0	1	1	0	6	1	1	1	1	1	0	1
0	1	1	1	7	1	0	0	0	0	1	1
1	0	0	0	8	1	1	1	1	1	1	1
1	0	0	1	9	1	1	1	1	0	1	1



Case Study (cont.)



B3	B2	B1	B0	Val	L1	L2	L3	L4	L5	L6	L7
0	0	0	0	0	1	0	1	1	1	1	1
0	0	0	1	1	0	0	0	0	0	1	1
0	0	1	0	2	1	1	1	0	1	1	0
0	0	1	1	3	1	1	1	0	0	1	1
0	1	0	0	4	0	1	0	1	0	1	1
0	1	0	1	5	1	1	1	1	0	0	1
0	1	1	0	6	1	1	1	1	1	0	1
0	1	1	1	7	1	0	0	0	0	1	1
1	0	0	0	8	1	1	1	1	1	1	1
1	0	0	1	9	1	1	1	1	0	1	1

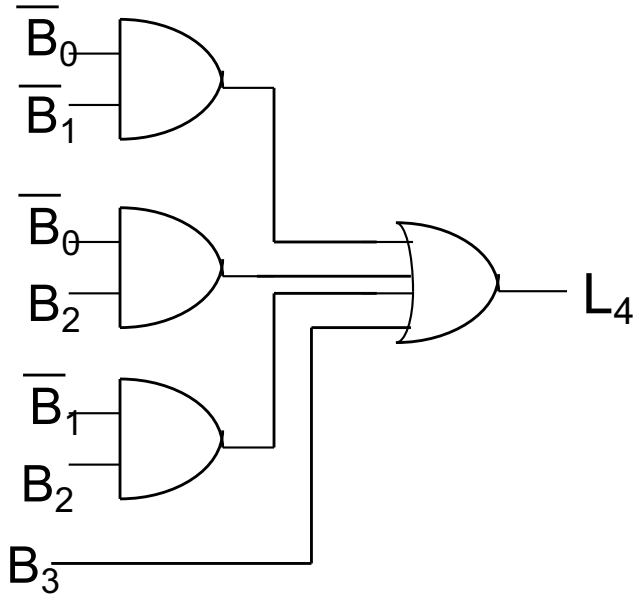


Case Study (cont.)

- Implement L4:

B3	B2	B1	B0	L4
0	0	0	0	1
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	0
1	0	0	0	1
1	0	0	1	1

Some gate level implementation of the Boolean function for L4



- This course will discuss how to optimize the logic mapping: less gate, less levels

Class Topics and Schedule

- Week 1: Introduction and Basics of Circuit with Transistors
- Week 2: Basic Combinational Logic Design
- Week 3: Logic Optimization using QM Method
- Week 4: Verilog 1 & 2
- Week 5: Synthesis of Digital Circuits and Midterm
- Week 6: Arithmetic Circuit Design
- Week 7: Sequential Circuit Design & Verilog 3
- Week 8: Finite State Machine & Verilog 4
- Week 9: FPGA & Digital System
    - This is a tentative schedule and subject to change