



고려대학교
KOREA UNIVERSITY

COMP427 Embedded Systems

Lecture 0. Course Introduction

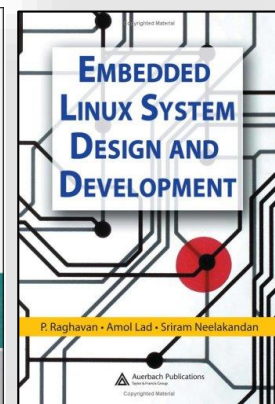
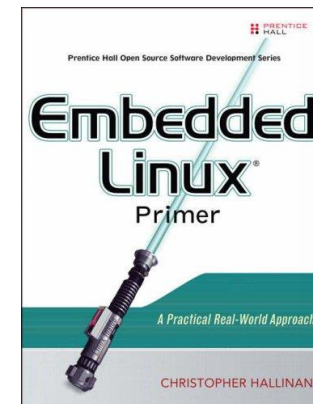
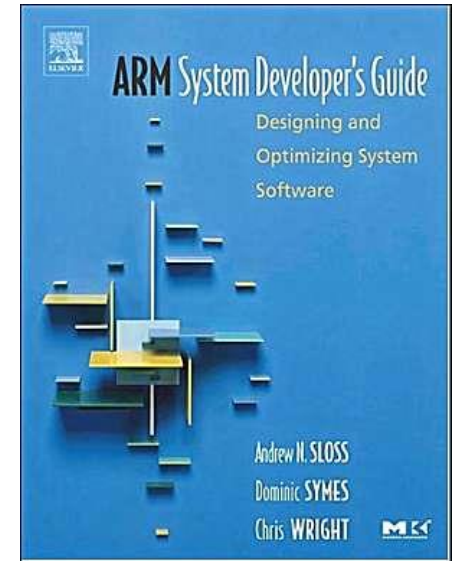
Prof. Taeweon Suh

Computer Science & Engineering

Korea University

Course Information

- Instructor
 - Prof. Taeweon Suh
- Textbook
 - ARM System Developer's Guide: Designing and Optimizing System Software by Andrew Sloss, Morgan Kaufman, 2004
- References
 - Embedded Linux Primer by Christopher Hallinan, Prentice Hall, 2006
 - Embedded Linux System Design and Development by P. Raghavan, Amol Lad and Sriram Neelakandan, Auerbach Publications, 2006
- Prerequisites
 - Computer Architecture, Operating Systems, C-programming
- Office hours
 - After class as needed
 - By appointment at Lyceum 307
- Lecture slides will be posted on the class web at <http://esca.korea.ac.kr/>
- Contact Information
 - suhtw@korea.ac.kr
 - 02-3290-2397



Preview of Embedded Systems

- Embedded systems are virtually everywhere in your life
 - Embedded systems cover a wide range of electronics gadgets such as iPhone, Android phone, GPS, Refrigerator, Washer, TV..



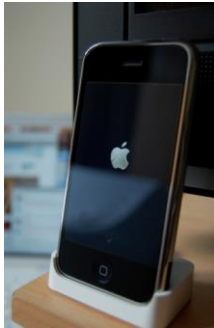
Preview of Embedded Systems

- Embedded System is **a special-purpose computer system** designed to perform one or a few dedicated functions - Wikipedia
 - In general, it does not provide programmability to users, as opposed to general purpose computer systems like PC



iPhone Generations

**Original iPhone
(iPhone 2G)**



June 2007

iPhone 3G



June 2008

iPhone 3GS



June 2009

iPhone 4



June 2010

iPhone 4S



Oct. 2011

iPhone 5



Sep. 2012

iPhone 5c iPhone 5s



Sep. 2013

iPhone 6 iPhone 6 Plus



Sep. 2014

http://apple.wikia.com/wiki/iPhone_3G

[http://en.wikipedia.org/wiki/History of the iPhone](http://en.wikipedia.org/wiki/History_of_the_iPhone)

Galaxy S Series

Galaxy S

- Android 2.3.6
- Single-core Cortex A8



June 2010

Galaxy S2

- Android 2.3 Gingerbread
- Dual-core Cortex A9



May 2011

Galaxy S3

- Android 4.0.4 Ice Cream Sandwich
- Dual-core Cortex A9



May 2012

Galaxy S4

- Android 4.2.2 Jelly Bean
- (Quad-core Cortex A15 & Quad-core Cortex-A7) or Quad-core Krait 300 (Qualcomm Snapdragon)

April 2013



Galaxy S5

- Android 4.4.2 KitKat
- (Quad-core Cortex A15 & Quad-core Cortex-A7) or Quad-core Krait 400 (Qualcomm Snapdragon)

April 2014



Galaxy S6 Edge

- Android 5.0 Lollipop
- Quad-core Cortex A53 & Quad-core Cortex-A57

March 2015



Smartphone War



HUAWEI



NOKIA
Connecting People



MOTOROLA

Google

lenovo



htc

quietly brilliant

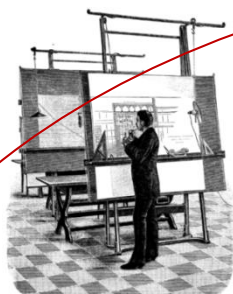


BlackBerry

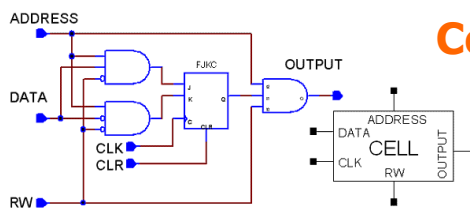


www.sleetherz.com/2011/10/smartphone-war-in-fatal-three-way-iphone-4s-razr-vs-galaxy-nexus/

Design Flow of Embedded Systems



**Planning & Architect
(modeling & simulation)**



ASIC/SoC design

**Hardware Design
with CAD tools**

Coverage of this course



**ASIC/SoC/AP
chip**



**System prototype
board**



**Hardware debugging &
Software development**



Final product

- ASIC: Application-Specific Integrated Circuit
- SoC: System-on-Chip

iPhone 4 Teardown

<http://www.ifixit.com/Teardown/iPhone-4-Teardown/3130/1>



http://news.cnet.com/8301-13924_3-20006904-64.html



<http://www.pcmag.com/encyclopedia/term/62034/antennagate>

GSM (Global System for Mobile communications): 2G, 3G, 4G ..

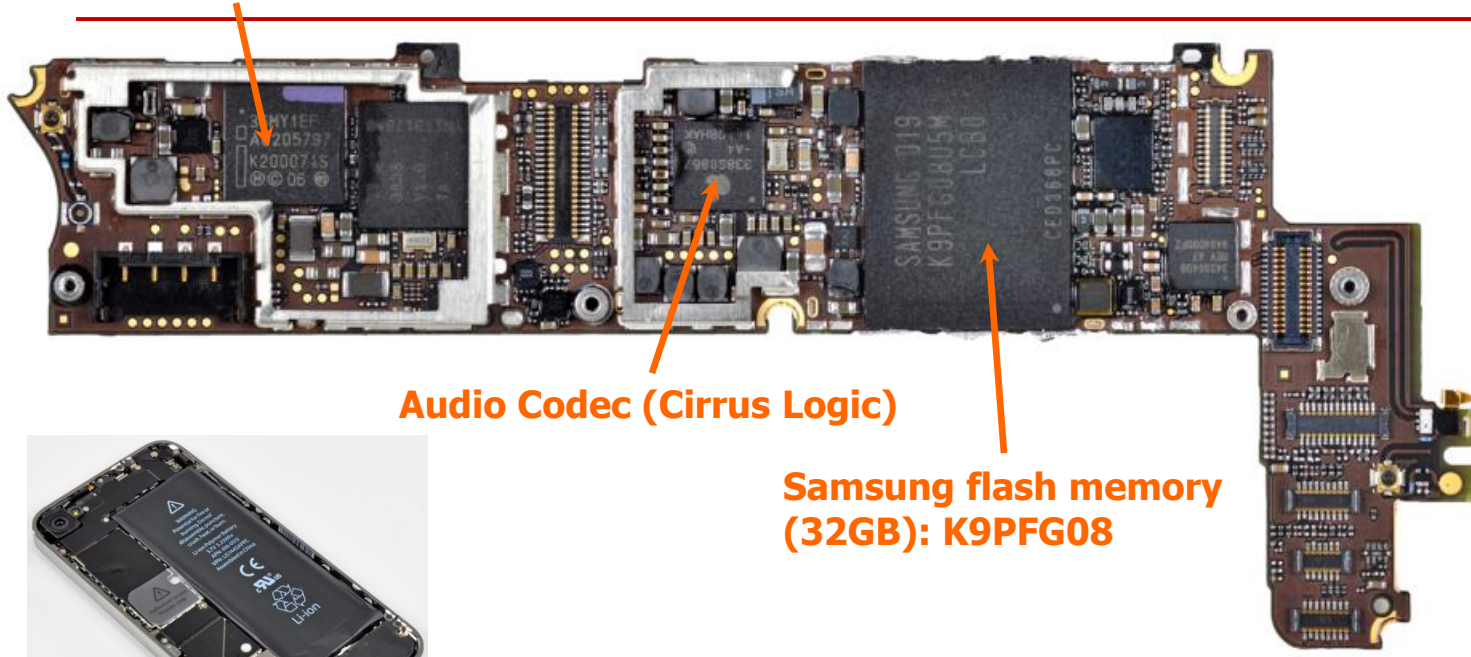
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UMTS (Universal Mobile Telecommunications Systems): one of 3G technologies being developed into 4G

Korea Univ

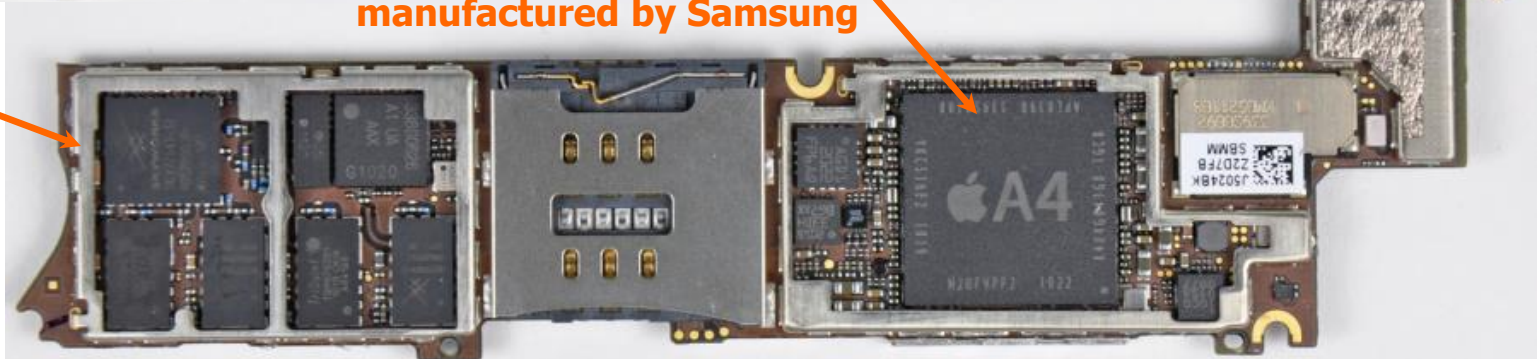
iPhone 4 Teardown

512MB Mobile DDR



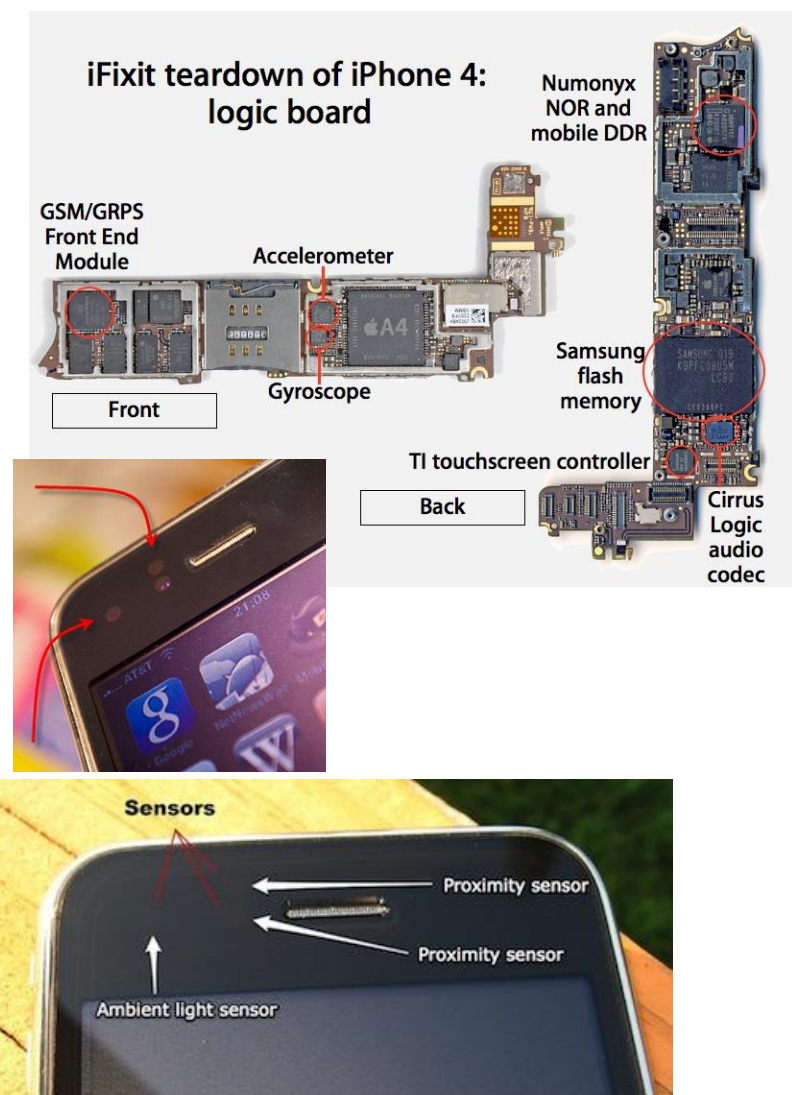
A4 Processor (ARM Cortex A8)
designed by Apple
manufactured by Samsung

GSM and
more

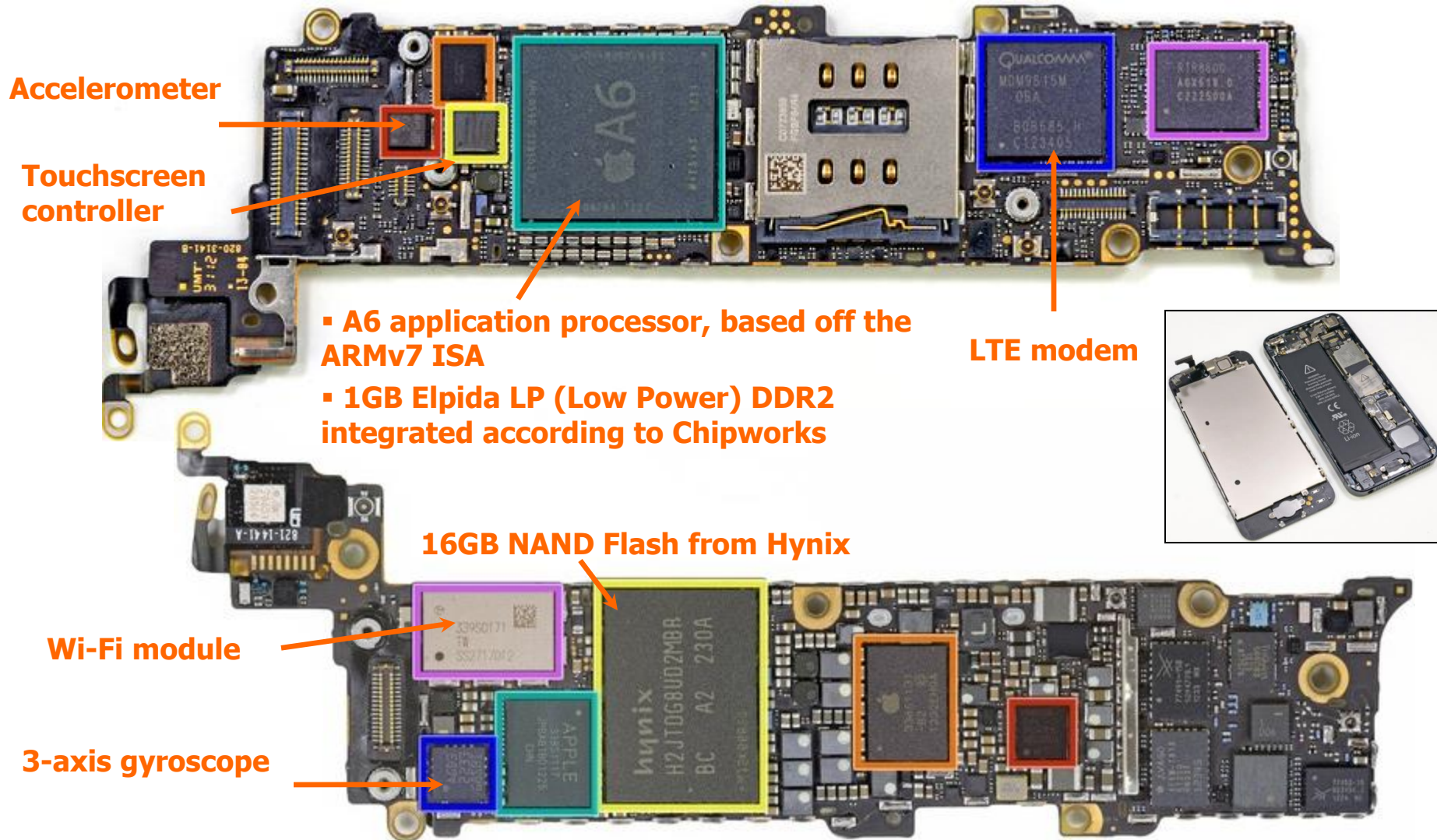


iPhone 4 Teardown

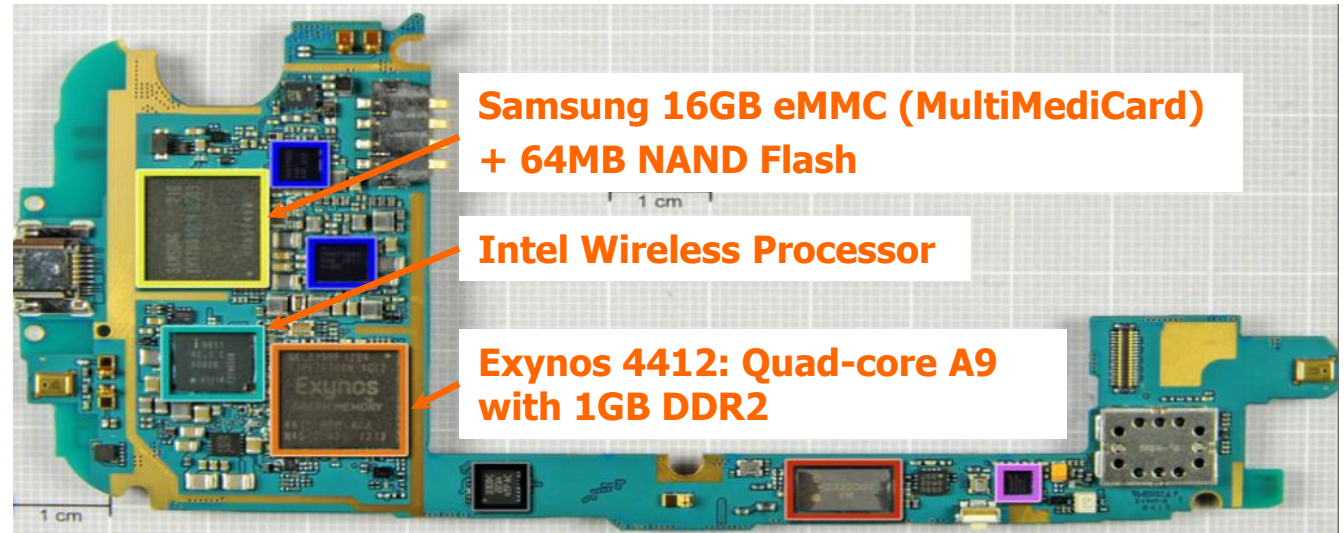
- **Accelerometer** detects when the user has rotated the device from portrait to landscape, then automatically changes the contents of the display accordingly
- **Proximity sensor** detects when you lift iPhone to your ear and immediately turns off the display to save power and prevent inadvertent touches until iPhone is moved away
- **Ambient light sensor** automatically adjusts the display's brightness to the appropriate level for the current ambient light, enhancing the user experience and saving power at the same time



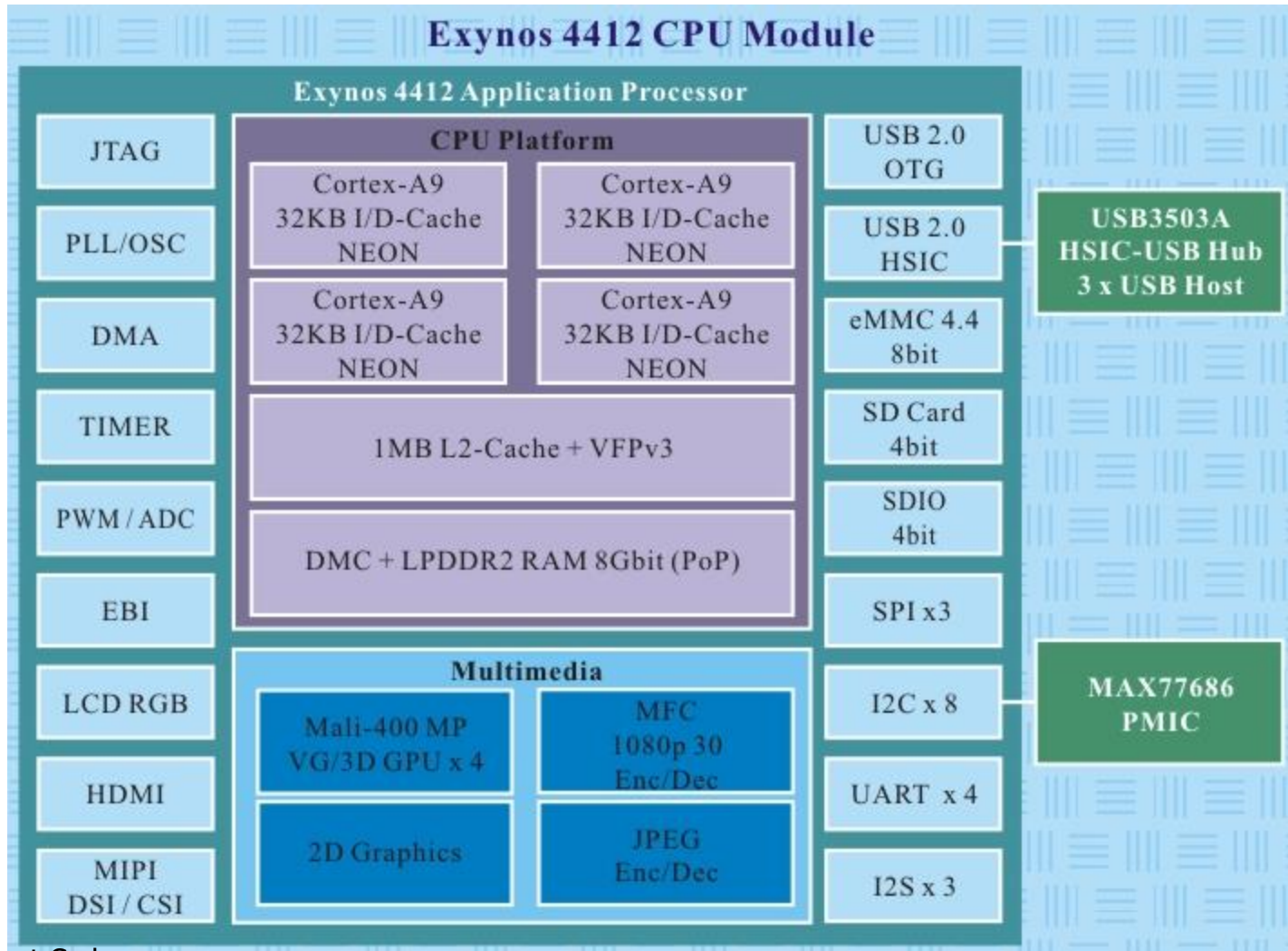
iPhone 5 Teardown



Galaxy S3 Teardown



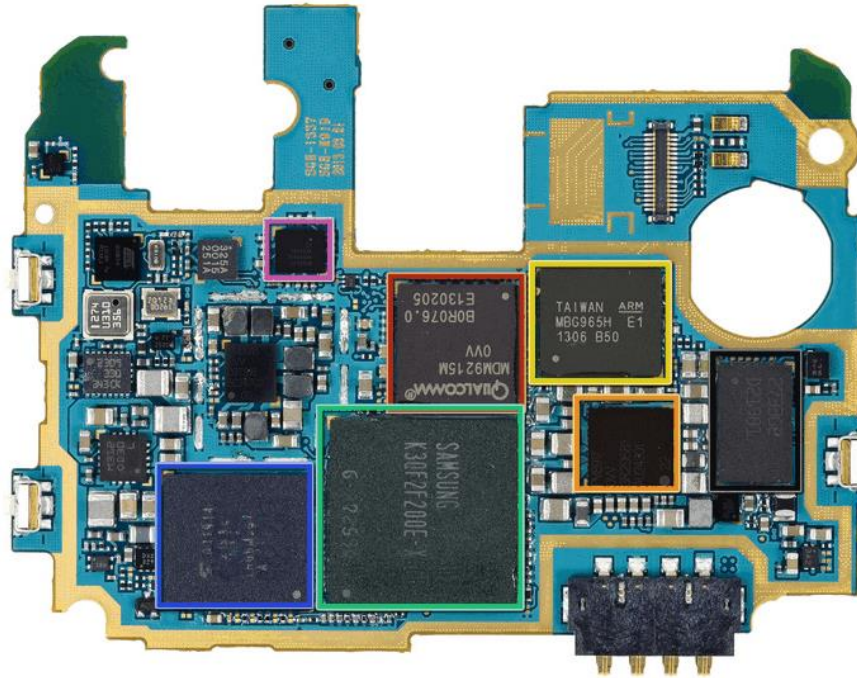
Exynos 4412 Block Diagram



MFC: Multi Format Codec

PoP: Package-on-Package

Galaxy S4 Teardown



- Front of motherboard:
 - Qualcomm MDM9215M 4G GSM/UMTS/LTE modem
 - Qualcomm PM8917 power management
 - ARM Holdings MBG965H
 - Samsung K3QF2F200E 2 GB LPDDR3 RAM (we suspect the Snapdragon 600 APQ8064T 1.9 GHz Quad-Core CPU lurks below)
 - Toshiba THGBM5G7A4JBA4W 16 GB eMMC (eMMC integrates a NAND flash memory and a controller chip in a single package)
 - Qualcomm WCD9310 audio codec
 - Broadcom BCM4335 Single-Chip 5G Wi-Fi MAC/Baseband/Radio (thanks to a tip from a user, and our friends at [chipworks](#), we believe there's something underneath this chip)

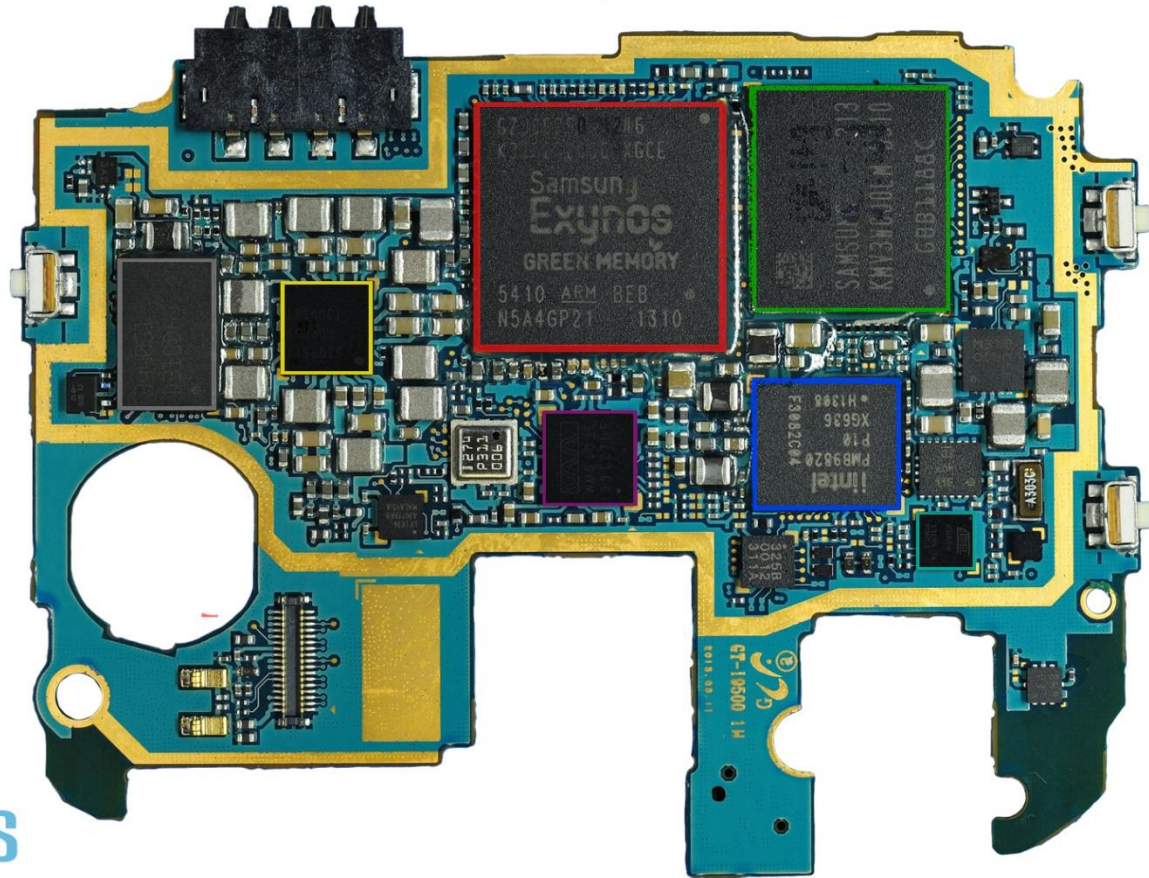
- Snapdragon 600 has Krait 300 CPU
- Krait has architectural similarities to ARM Cortex-A15 -- Wikipedia

Galaxy S4 Teardown

COMPONENTS

Samsung Galaxy S4 COMMUNICATIONS BOARD, FRONT

- Samsung Exynos 5410
Exynos Octa Eight-Core processor
- Samsung K3QF2F200C-XGCE
2GB LP DDR3 (K4E4E324EB die) mobile DRAM
- Intel PMB9820
X-GOLD 636 Baseband Processor
- Samsung KMV3W000LM-B310
Multichip Memory - 64 MB Mobile DDR SDRAM, 16 GB MLC NAND Flash, Controller
- Samsung S2MPS11
Power Management IC
- Wolfson Micro WM5102E
Audio Hub CODEC with Voice Processor DSP
- Atmel UC128L5-U
32 bit Microcontroller with 128KB Flash (custom package)
- Broadcom BCM4335
Wi-Fi 802.11 a/b/g/n/ac, dual-band, DLNA, Wi-Fi Direct, Wi-Fi hotspot all-in-one IC

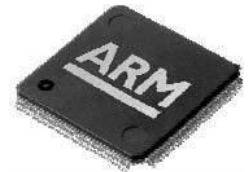


TECHINSIGHTS

■ Exynos 5 Octa (Exynos 5410): quad-core Cortex-A15 and quad-core Cortex-A7 -- Wikipedia

Objective

- **Understand embedded systems**
 - Differences between general purpose computer systems and embedded systems
 - Characteristics of embedded systems
- **Experience an embedded system with hands-on labs**
 - Take a simple embedded system and play with it throughout the course
 - Introduction to AT91 SoC and ARM
 - Introduction to Virtual Platform
 - And then Lab, Lab, Lab...
 - As a byproduct, you will get familiarized with Linux environment



This Course

- Embedded Systems
 - **Hardware:** As shown in the iPhone 5 (or Galaxy S3) example, hardware is nothing but a combination of CPU(s), memory, and (lots of) peripheral devices
 - **Software:** Operating systems for high and mid-end embedded systems (ex: Android or iOS) + Apps
- This course
 - **Hardware:** we are going to use AT91 as a hardware platform, which you can think as a stripped-down version of iPhone 5
 - **Software:** Embedded Linux + Apps



Grading Policy

- Midterm Exam: 30%
- Final Project: 40%
- Class Presentations: 20%
- Assignments: 10%
- **Fail rule**
 - You will be given an "F" if you are absent more than 3 times
 - 2 late show-ups will be counted as 1 absence

Backup Slides

iPhone 4 BOM (Bill of Materials)

Preliminary Bill of Materials (BOM) Estimate for the 16Gbyte Version of the iPhone 4
(Costs in U.S. Dollars)*

Subsection	Part Description	Part Supplier/Part Details	Component Cost
Applications Processor	Applications Processor	Samsung A4 APL0398 45nm, PoP	\$10.75
	DRAM Memory	SDRAM, 4Gb Mobile DDR, PoP Samsung K4XKG643GB (Samsung dies, 2 x 2Gb)	\$13.80
	Misc. Applications Processor Components	Discretes, Passives, etc.	\$0.50
Memory	Flash	Samsung NAND Flash 16GB MLC K9HGD08U5M-LCB0	\$27.00
	Misc. Memory Components	Discretes, Passives, etc.	\$0.30
	Baseband	Infineon 337S3833	\$11.72
Radio Frequency	Transceiver	HSDPA/HSUPA/WCDMA/EDGE	\$2.33
	Memory	Intel (Numonyx?) MCP 128Mb NOR Flash + 128Mb Mobile DDR (DDR is Elpida)	\$2.70
	Power Mgmt.	n/a	
	PAM	Skyworks SKY77541-32 Transmit Module Quad-Band GSM/EDGE PAM + Antenna Switch	<included in Misc. Costs below>
	PAM	Skyworks SKY77459-17 Transmit Module Single-Band WCDMA/HSPA PAM + Duplexer	<included in Misc. Costs below>
	PAM	Skyworks SKY77452-20 Transmit Module Single-Band WCDMA/HSPA PAM + Duplexer	<included in Misc. Costs below>
	PAM	TriQuint TQM676091 Transmit Module Single-Band WCDMA/HSPA PAM + Duplexer	<included in Misc. Costs below>
	PAM	TriQuint TQM666092 Transmit Module Single-Band WCDMA/HSPA PAM + BAW Duplexer	<included in Misc. Costs below>
	FEM	n/a	
	SAW Module	Murata	<included in Misc. Costs below>
Power Management	Misc. RF Components	PAMs, Modules, Discretes, Passives, etc.	\$8.25
	Main PM Device	Dialog D1815A 338S0867-A4 Main Pwr Mgmt	\$2.03
	Misc. Power Mgmt.	Discretes, Passives, etc.	\$1.90

Connectivity	WiFi/BT	Broadcom BCM4329 Module WLAN 02.11a/b/g/n, Bluetooth V2.1+EDR, FM/RDS/RBDS Rcvr	\$7.80
	GPS	Broadcom BCM4750	\$1.75
	Misc. Connectivity Components	Discretes, Passives, etc.	\$0.80
Interface & Sensors	Touchscreen Controller	Texas Instruments 343S0499 (F761586C)	\$1.23
	Audio CODEC	Cirrus Logic 343S0589 (CL11495B0)	\$1.15
	E-Compass	AKM AK8975 3-Axis	\$0.70
	Accelerometer	ST Micro LIS331DLH 3-Axis	\$0.65
	Gyroscope	ST Micro L3G4200D Digital 3-Axis	\$2.60
	Misc. Interface & Sensor Components	Discretes, Passives, etc.	\$3.80
Display/Camera	Display	3.5" Diag, LTPS LCD, 960x640 Pixels LG (or poss. TMD)	\$28.50
	Touch Screen	Capacitive Glass, "Reinforced" Wintek or TPK/Balda	\$10.00
	Camera	SMP Auto-Focus	\$9.75
Battery	Camera (secondary)	VGA Auto-Focus	\$1.00
	Battery	1400mAh	\$5.80
Other	Mechanicals	Enclosure, Metals, Plastics, Hardware, etc.	\$10.80
	Electro-Mechanicals	PCBs, Acoustics, Connectors, etc.	\$14.40
TOTAL	Misc.	Accessories, Literature, Box Contents	\$5.50
			\$187.51

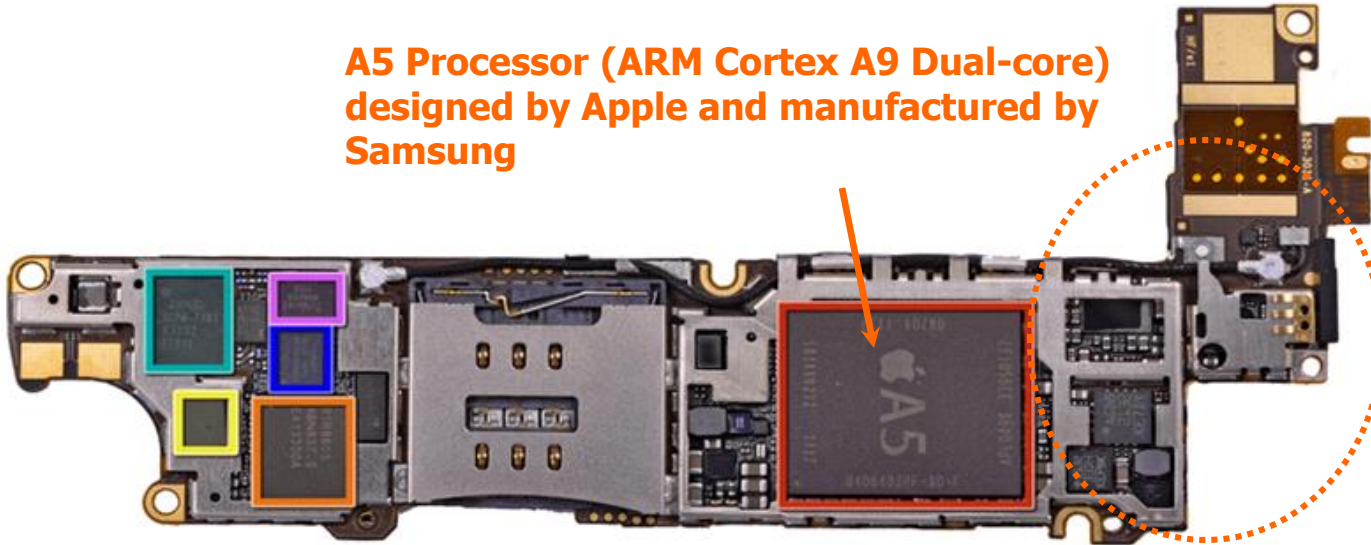
Teardown costs account only for components and do not include other expenses such as manufacturing, software, royalties and licensing fees

16 GB iPhone 4: Estimation as of June 2010 by isuppli.com

<http://www.isuppli.com/Teardowns/News/Pages/iPhone-4-Carries-Bill-of-Materials-of-187-51-According-to-iSuppli.aspx>

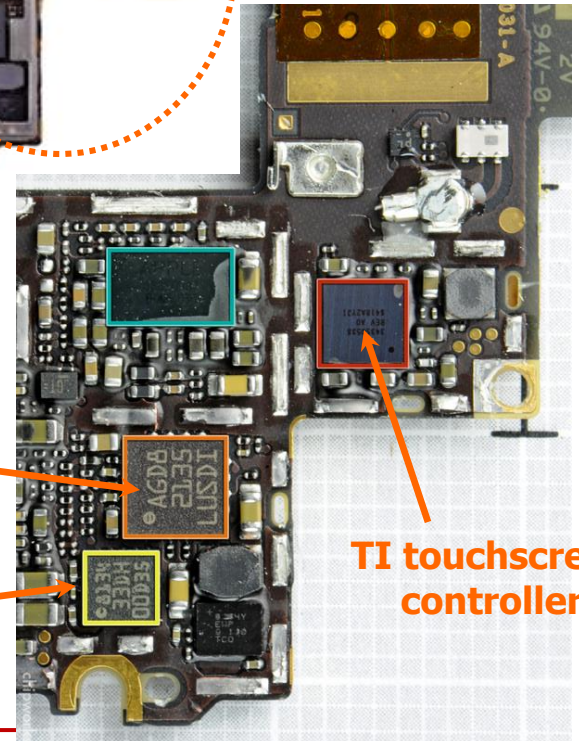
iPhone 4S

**A5 Processor (ARM Cortex A9 Dual-core)
designed by Apple and manufactured by
Samsung**



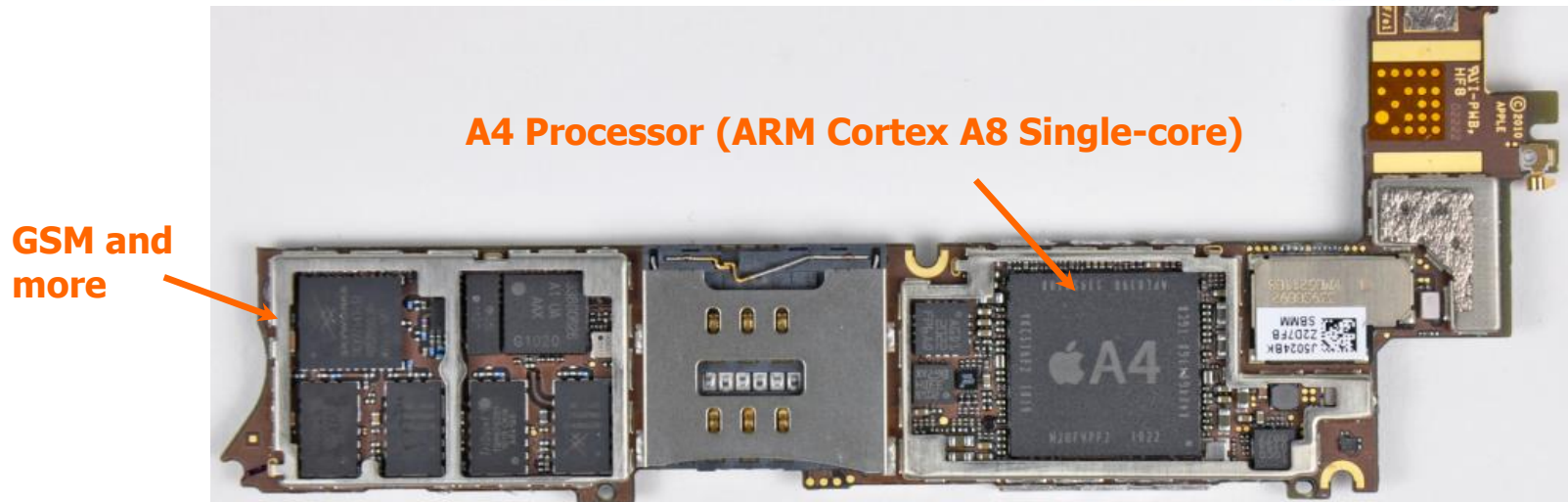
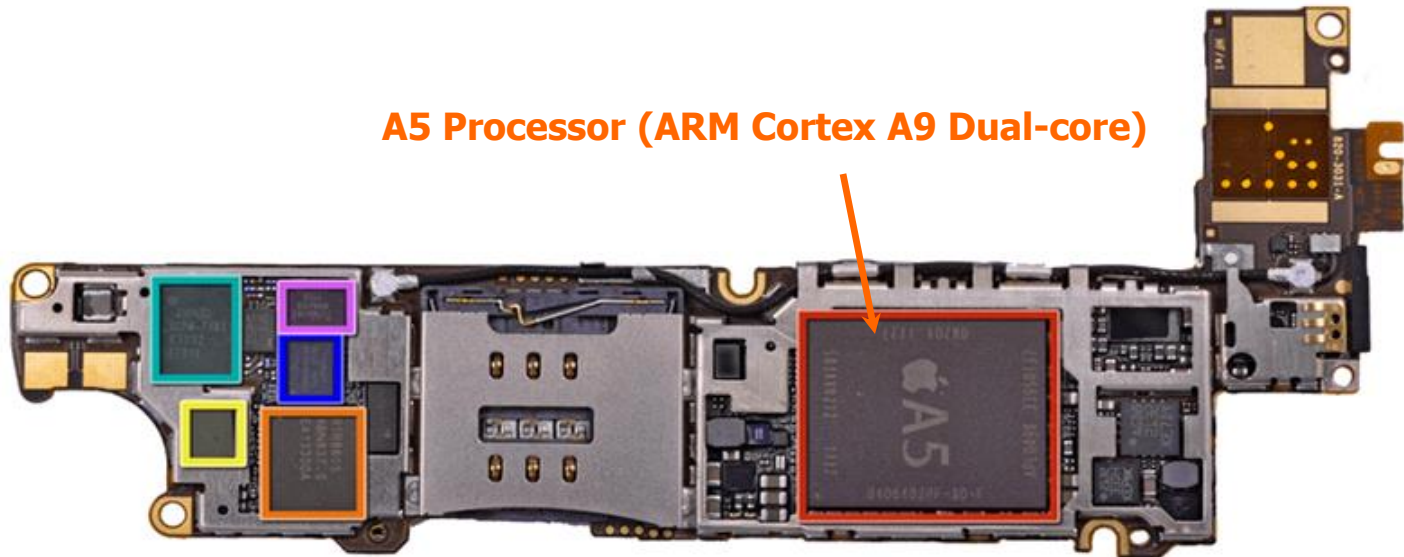
STMicroelectronics' Gyroscope

**STMicroelectronics' 3-axis
accelerometer**



**TI touchscreen
controller**

iPhone 4S vs iPhone 4



Cortex A8 vs A9

- **Cortex A8**

- Frequency from 600 MHz to 1 GHz and above
- **Superscalar dual-issue microarchitecture**
- NEON SIMD instruction set extension (optional)
- VFPv3 Floating Point Unit (optional)
- Thumb-2 instruction set encoding
- Jazelle RCT
- Advanced branch prediction unit with >95% accuracy
- Integrated level 2 Cache (0-4 MB)
- 2.0 DMIPS / MHz

- **Cortex A9 MCore**

- Provides **up to 4 cache coherent Cortex A9 cores**
- **Out-of-order speculative issue superscalar** execution pipeline giving 2.50 DMIPS/MHz/core.
- NEON SIMD instruction set extension performing up to 16 operations per instruction (optional).
- High performance VFPv3 floating point unit doubling the performance of previous ARM FPUs (optional).
- Thumb-2 instruction set encoding reduces the size of programs with little impact on performance.
- TrustZone security extensions.
- Jazelle DBX support for Java execution.
- Jazelle RCT for JIT compilation.
- Program Trace Macrocell and CoreSight Design Kit for unobtrusive tracing of instruction execution.
- L2 cache controller (0-4 MB).

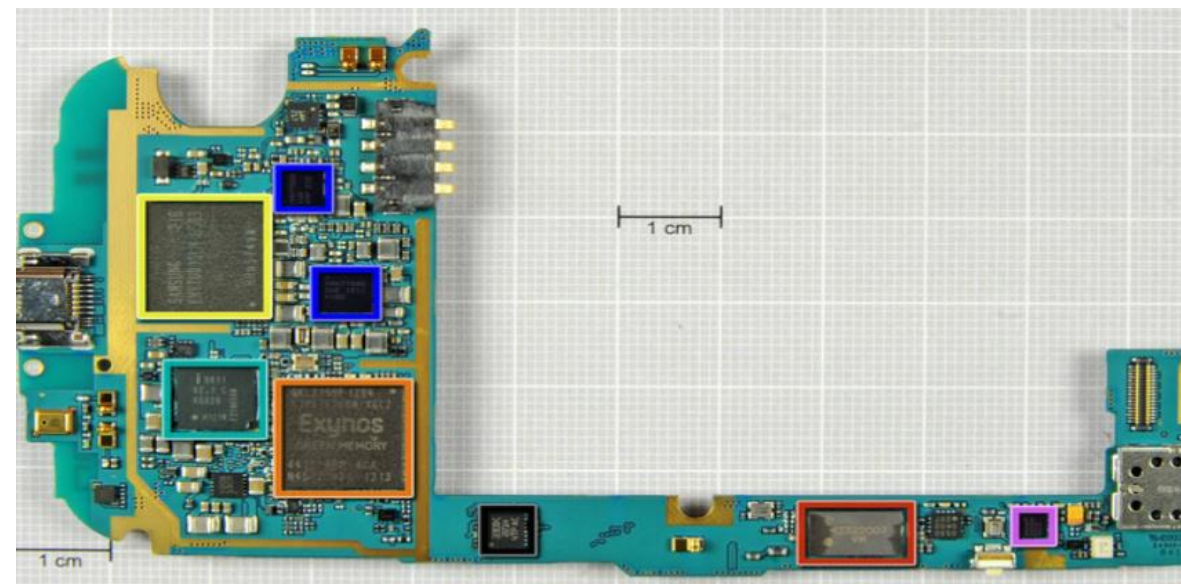
S5PC210 Exynos 4210 Processor in Galaxy Note

Samsung S5PC210 Exynos 4210 RISC Multi-core Application Processor

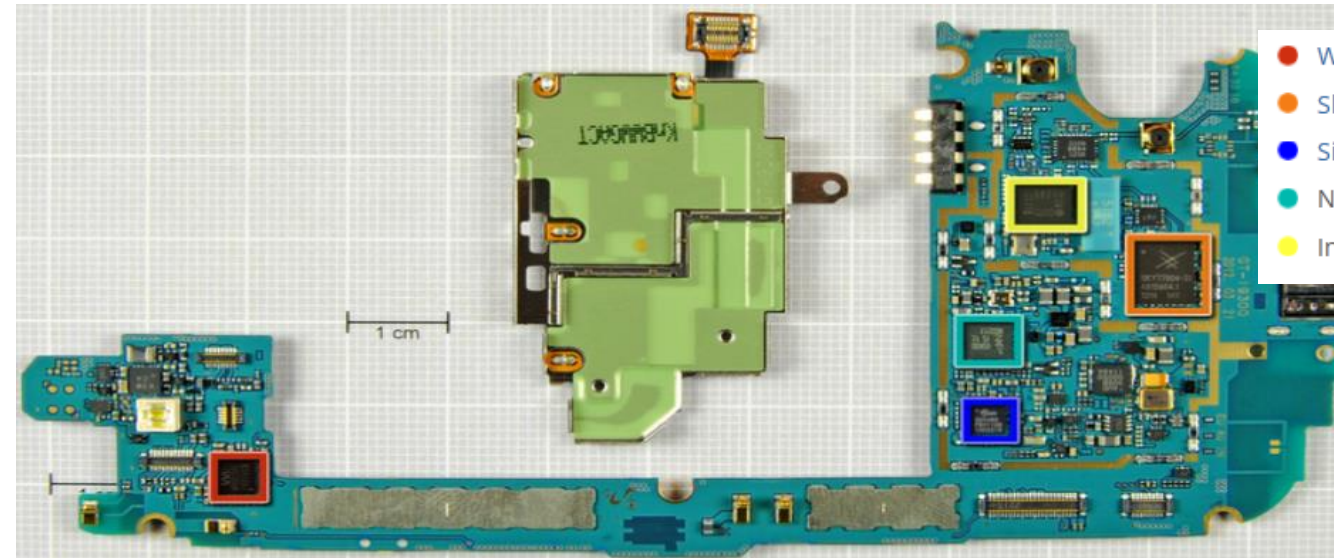
Simplified Technical Specifications

Type:	S5PC210 Exynos 4210
Manufacturer:	Samsung
Year Released:	2011
Codename:	Orion
Predecessor:	32bit Samsung-Intrinsity S5PC110
Characteristics	
CPU Structure (complexity):	RISC
Width of Machine Word:	32 bit
Primary (RAM) Data bus:	32 bit
Instruction Set	
Supported Instruction Set(s):	ARMv7
Clock Frequencies	
Recommended Maximum Clock Frequency:	1200 MHz
Caches	
Level 1 cache per Core:	32KiB data cache / 32 KiB instruction cache
Level 2 cache per Core:	1024 KiB
Technology	
Semiconductor Technology:	CMOS
Minimum Feature Size:	45 nm
Contacts:	756 pins
Additional Details	
Special Features:	dual ARM Cortex-A9 Harvard Superscalar processor core, 9-stage pipeline, 64/32-bit Multi-layer AHB/AXI bus, ARM TrustZone, ARM NEON SIMD engine, SDRAM, 2x 32-bit DDR2, LPDDR2, DDR3 SDRAM interface, NAND flash, moviNAND, SATA, eMMC interface, embedded GPS module, HDMI 1.3a, triple display controller, 1080p 30fps video encode, 1080p 60fps video decode, audio subsystem, ARM Mali-400 GPU
Related Page:	http://www.samsung.com/global/business/semiconductor/productList.do?fmly_id=844&xFmly_id=229
Datasheet Time:	Sep 14, 10 22:52:50
Datasheet Views:	30144 views

Galaxy S3 Teardown



- Murata M2322007 WiFi Module
- Samsung Exynos 4412 quad-core A9 processor with 1 GB LP DDR2 Green Memory (K3PE7E700M-XGC2)
- Samsung KMVTU000LM eMMC(16GB)+MDDR (64MB) NAND Flash
- Intel Wireless PMB9811X Gold Baseband processor
- MAX77693 and MAX77686
- Broadcom BCM47511 Integrated Monolithic GNSS Receiver
- 330DC 2214 4TP AC

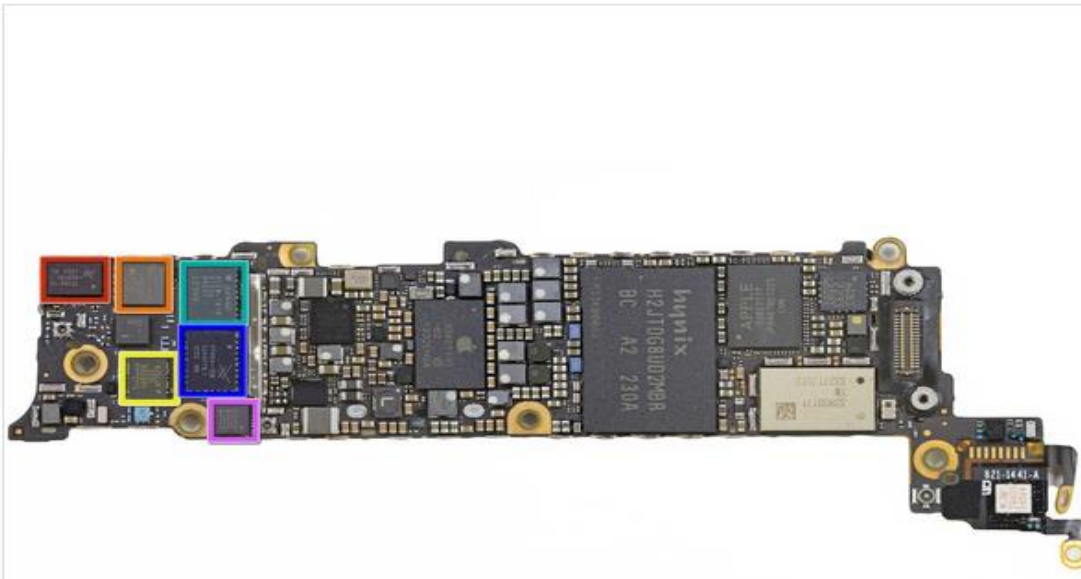


- Wolfson Microelectronics WM1811 stereo codec
- Skyworks SKY77604 Multi-Band Power amplifier
- Silicon Image 9244 low-power MHL Transmitter
- NXP PN544 NFC Chip.
- Infineon PMB5712 RF transceiver

Galaxy Note 2 Teardown



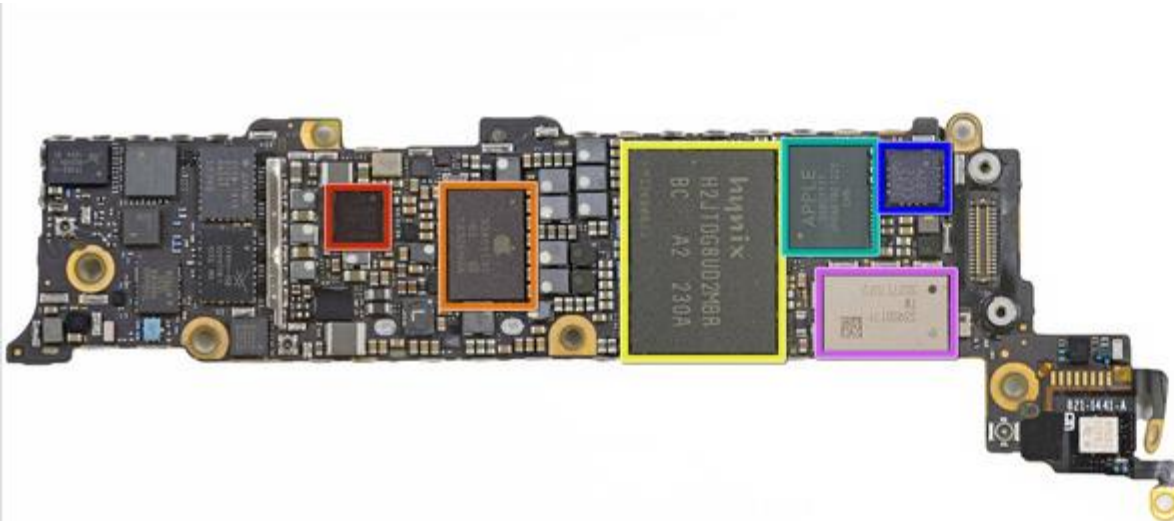
iPhone 5 Teardown



Step 14

Edit

- The underside of the logic board is teeming with components.
- Skyworks 77352-15 GSM/GPRS/EDGE power amplifier module
- SWUA 147 228 is an RF antenna switch module
- Triquint 666083-1229 WCDMA / HSPA power amplifier / duplexer module for the UMTS band
- Avago AFEM-7813 dual-band LTE B1/B3 PA+FBAR duplexer module
- Skyworks 77491-158 CDMA power amplifier module
- Avago A5613 ACPM-5613 LTE band 13 power amplifier

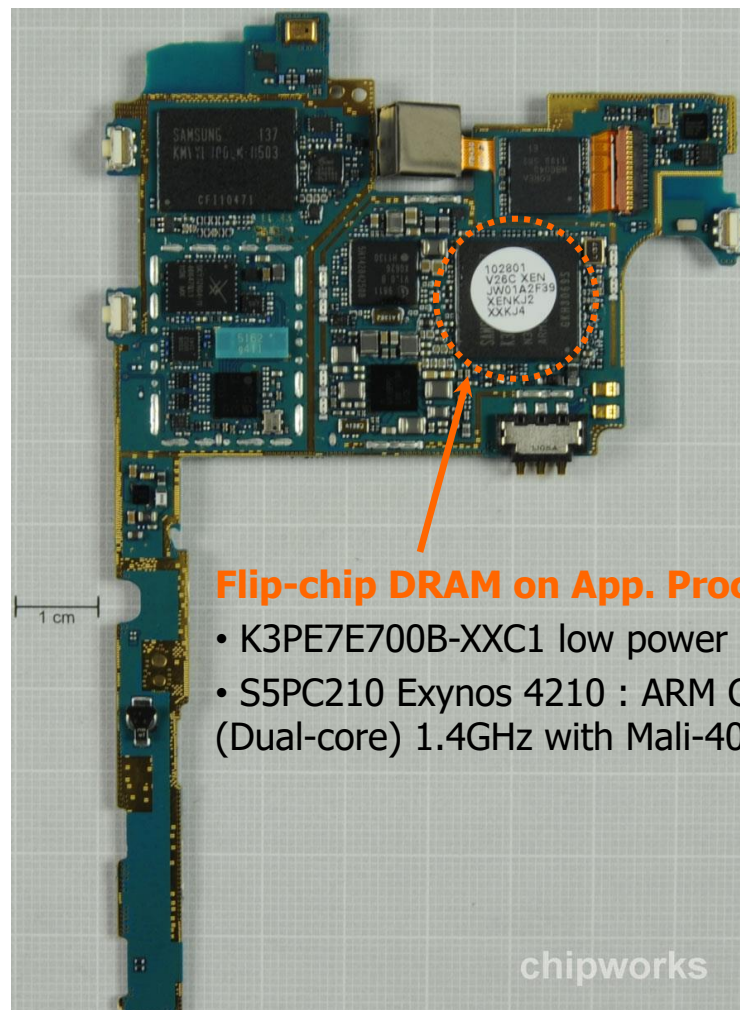


Step 15

Edit

- More chips on the underside of the logic board:
- Qualcomm PM8018 RF power management IC
- Hynix H2JTDG2MBR 128 Gb (16 GB) NAND flash
- Apple 33851131 dialog power management IC*
- Apple 33851117 Cirrus Logic Class D Amplifiers. The die inside is a Cirrus Logic device (second image) but it does not look like the audio codec.
- STMicroelectronics L3G4200D (AGD5/2235/G8SBI) low-power three-axis gyroscope—same as seen in the iPhone 4S, iPad 2, and other leading smart phones
- Murata 33950171 Wi-Fi module

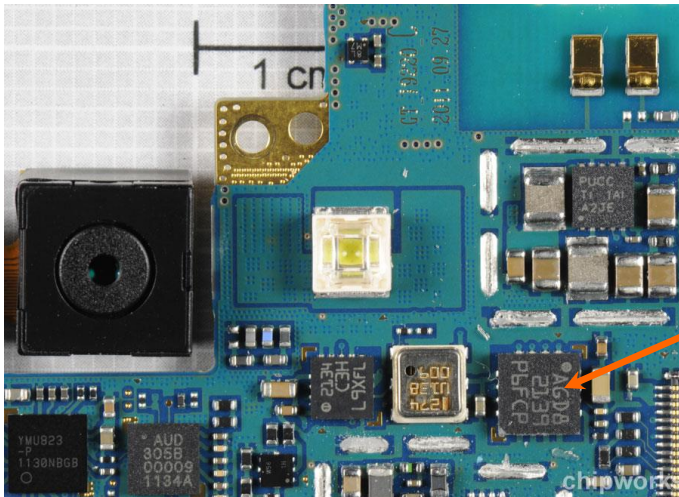
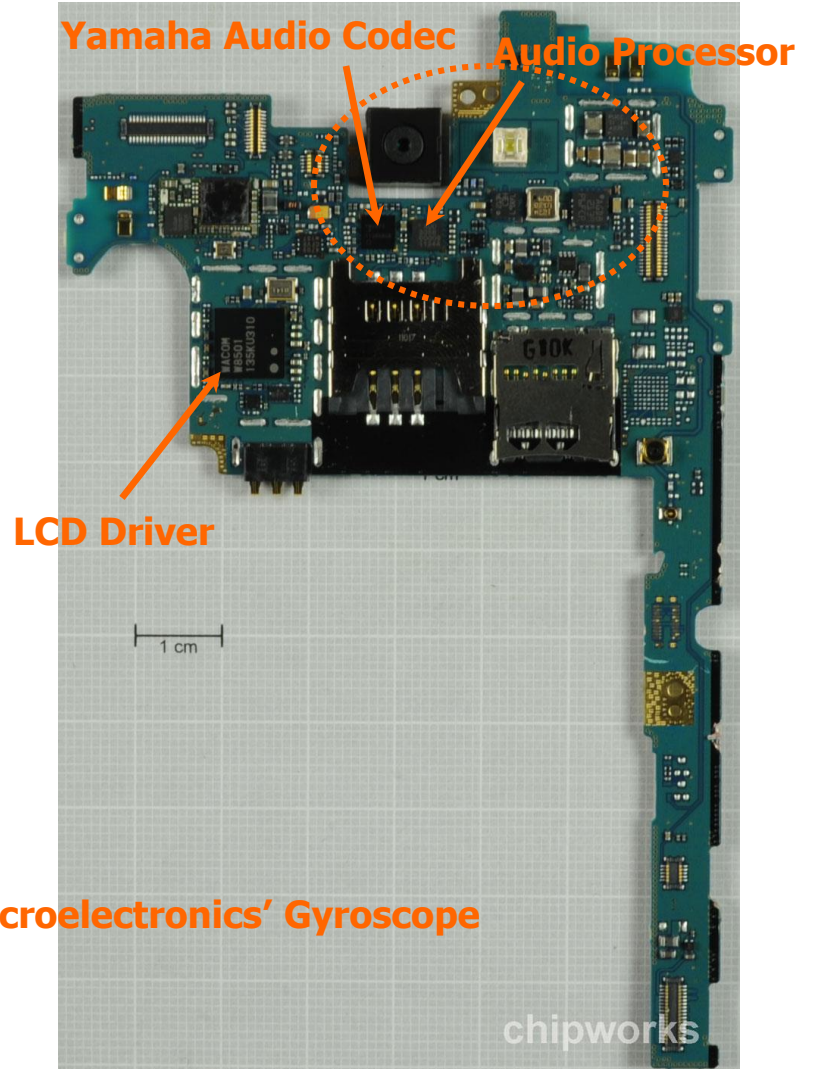
Galaxy Note Teardown



Flip-chip DRAM on App. Processor

- K3PE7E700B-XXC1 low power 1GB DDR2
- S5PC210 Exynos 4210 : ARM Cortex A9 (Dual-core) 1.4GHz with Mali-400 MP GPU

Galaxy Note Teardown



STMicroelectronics' Gyroscope