Semiconductor Technology Primer

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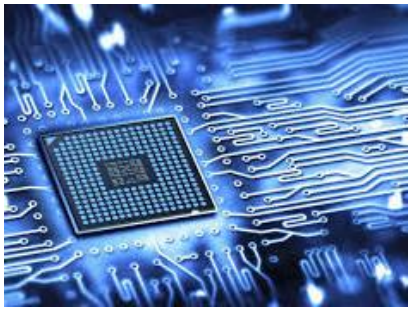
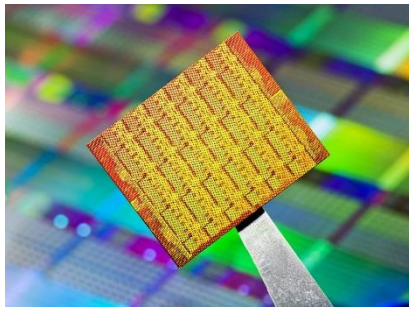
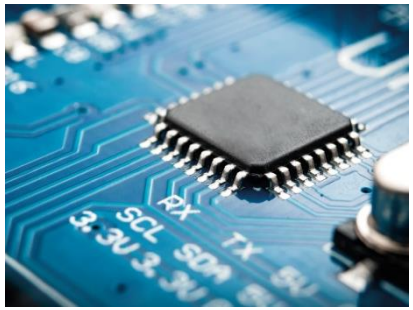
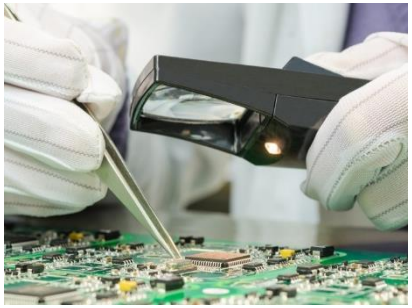
Introduction to Semiconductor Technology

A Commoditized Industry?

Chips Everywhere




Introductory Questions

- How can something as small as semiconductor chips be differentiated?
- Is it efficient to have a large number of companies in what seems to be a largely commoditized space?
- Is industry consolidation likely to continue in the global semiconductor market?

A Bird's Eye View of the Semiconductor Industry

There are multiple product categories in which global players operate

Analog

Microcomponents

Digital Logic

Memory

Discretes and Optoelectronics

Sources: Capital IQ, Wall Street Research

A Bird's Eye View of the Semiconductor Industry (cont'd)

Semiconductor companies can also be segmented by the various end markets they serve

Computing

Wireless

Networking

Digital Consumer

Telecom/Datacom

Automotive

Sources: Capital IQ, Wall Street Research

A Deeper Dive Into Semiconductor Applications

Prevalence of Semiconductors in our Everyday Lives

Computing

- PCs and servers
- PC displays
- Hard disk drives
- Printers
- Multi-function peripherals

Wireless

- *Wireless Handsets:* Driven by device replacement cycles
- *Wireless Infrastructure:* Driven by carrier build-out programs and network upgrades
- *LTE:* Network standard with high data rates and spectrum efficiency

Networking

- *Ethernet (LAN):* Connect PCs in a single physical location
- *Wireless LAN:* Connect users in a single location via radio waves
- *Bluetooth:* Connect two devices in close proximity wirelessly
- *Enterprise storage networks*

Consumer

- Smart home devices
- Gaming consoles
- Digital set-top boxes
- DVD and MP3 players

Telecom / Datacom

- *Modems:* Connect customers to service provider network
- *PON:* Connect customers to the Internet using optical fiber
- *Communications Infrastructure:* Support voice and data networks spanning long distances

Automotive

- Advanced driver assistance systems (ADAS)
- Airbags
- Anti-lock braking systems (ABS)
- Infotainment
- Remote / keyless entry

Source: Wall Street Research

Taking a Step Back: Semiconductor Basics

Understanding Key Terms and Distinctions

- A **semiconductor** is a solid-state substance that is halfway charged between a conductor and an insulator; the movement of electricity is carefully controlled through a combination of conductive, semiconductor and insulator material
- A **transistor** is the basic element used in building semiconductor devices, acting as an on / off switch located between two charged regions known as a “source” and “drain”
  - A transistor array is etched onto a rectangular piece of **silicon** called a **die**; the die is housed in a plastic or ceramic **package** and is supported by many tiny wires (**wire bonding**)
- **Discretes** are the simplest type of semiconductor devices consisting of a single transistor
- **Integrated circuits (ICs)** are complex semiconductor devices that combine many transistors to perform advanced processing or storage functions; the most integrated of these devices are known as **system-on-a-chip devices (SoCs)**
- **Wafer fabrication** is a manufacturing process where thin slices of silicon (**wafers**) undergo chemical reactions that etch a transistor array pattern on the wafer; it is also known as **front-end manufacturing**, which precedes **assembly (back-end)**
  - A factory that manufactures semiconductors is known as a **wafer fab**
- **Manufacturing Strategies**
  - **Foundries** are specialized third-party manufacturers that perform wafer fabrication or assembly

    tsmc UMC GLOBAL FOUNDRIES ASE GROUP
  - **Fabless** companies design semiconductor devices but contract the manufacturing out to others

    BROADCOM QUALCOMM NVIDIA MEDIATEK
  - **Integrated Device Manufacturers (IDMs)** design and manufacture their own devices

    intel Texas Instruments SAMSUNG RENESAS

Sources: ST Micro, Wall Street Research

Semiconductor Basics (cont'd)

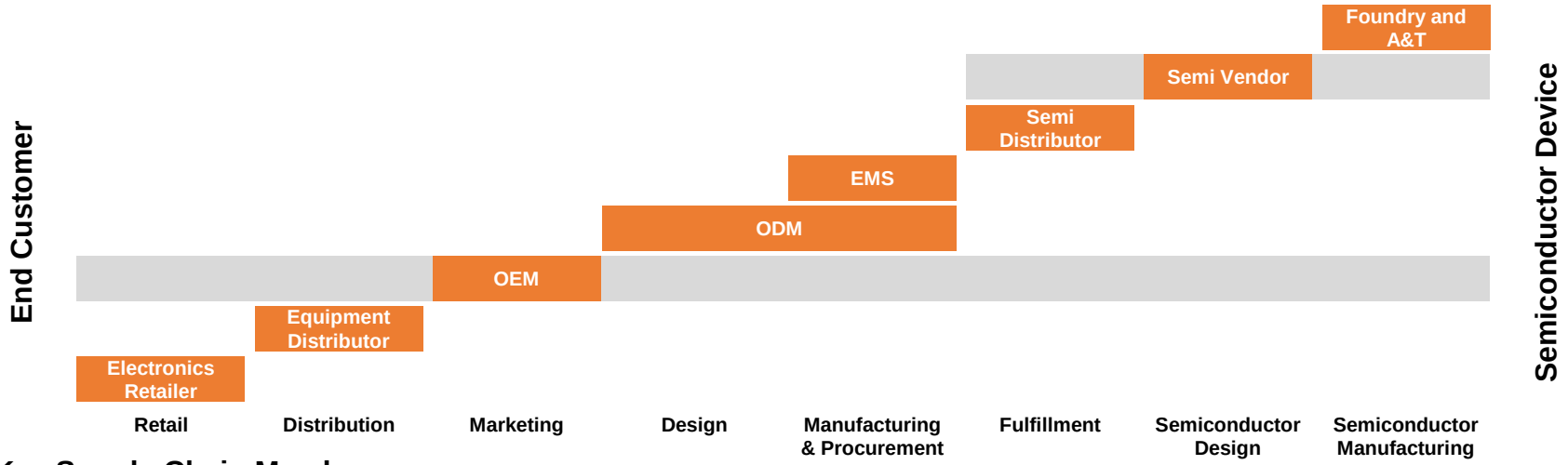
Summary of Product Categories

Analog	▪ Devices used to process, convert and create real world signals – while digital circuits operate by determining the absence or presence of an electrical charge ("1s" and "0s"), analog circuits deal with **actual voltages** or other **electrical properties** in circuits ▪ **Two types:** standard linear integrated circuits (SLICs), application-specific standard products (ASSPs)
Microcomponents	▪ Programmable devices that perform intensive compute processing and system control – they run software that is very customizable and can change the function of the device ▪ There are three types of microcomponents: **microprocessors** (CPUs or MPUs), **microcontrollers** (MCUs), and **digital signal processors** (DSPs)
Digital Logic	▪ Devices that perform specialized digital processing within a system – includes all non-microcomponent logic devices, generally prioritizing performance, cost and power management over programmability ▪ **Five key markets:** special purpose logic, display drivers, general purpose logic, application-specific integrated circuits (ASICs), and programmable logic devices (PLDs)
Memory	▪ Used to store data either temporarily or permanently ▪ **Volatile memory** loses stored information when the power is lost (i.e., DRAM, SRAM) ▪ **Non-volatile memory** retains information when the system is powered off (i.e., flash, mask ROM, EPROM, EEPROM)
Discretes, Optoelectronics and Sensors	▪ This category includes all non-integrated circuit semiconductor devices ▪ **Discretes** contain just a single transistor in a package ▪ **Optoelectronics** are specialized discretes designed to emit and detect light ▪ **Sensors** measure physical, chemical or biological properties

Source: Wall Street Research

Semiconductor Basics (cont'd)

Supply Chain Overview[1]



Key Supply Chain Members

Foundry and Assembly & Testing: Perform manufacturing, assembly and testing of semiconductor devices

Vendor: Perform chip design and marketing; can be an IDM, foundry or a fabless company; can sell parts directly to OEMs, ODMs or EMS, or use a distributor (or a combination of both)

Distributor: Carry inventory, handle import logistics for international shipments and reach smaller customers

Electronic Manufacturing Services (EMS): Perform manufacturing on behalf of OEMs

Original Device Manufacturer (ODM): Similar to EMS but also handle aspects of the design and procurement process

Original Equipment Manufacturer (OEM): Electronics provider who designs and markets products to end customers and service providers; can adopt various levels of vertical integration; increasing focus on building software and service businesses, speeding up time-to-market, and establishing new channels

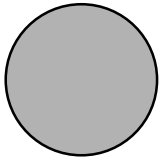
Equipment Distributor and Electronics Retailer: Focused on reaching customers through in-store and online sales

Source: Wall Street Research
1. Primary functions are denoted in orange, while additional functions are shown in grey

The Science Behind Semiconductors

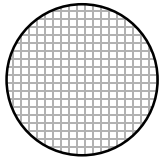
Breaking Down the Manufacturing Process

Wafer Manufacturing



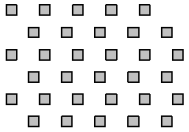
Silicon wafers are created from raw silicon via crystal pulling and slicing, wafer polishing, cleaning and oxidization. Separate wafer companies perform this process.

Wafer Processing (Front-End)



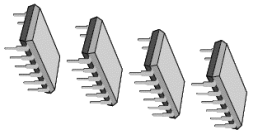
Wafers are run through a series of chemical processes to etch the transistor array and interconnects. This is the longest, most complex and costly stage.

Dicing



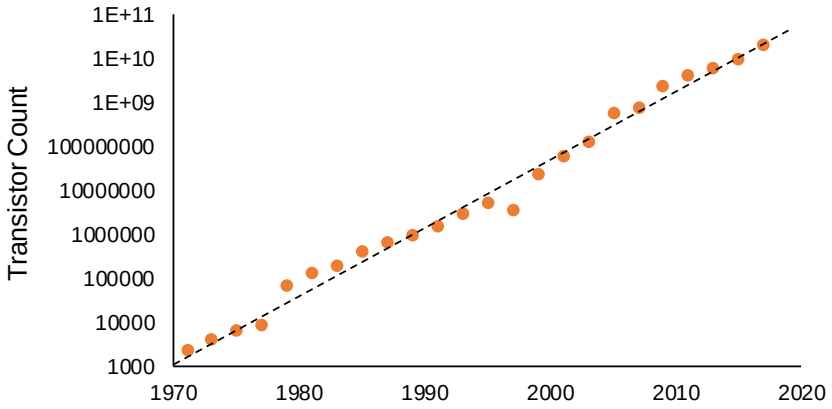
The processed wafer is chopped into individual die using a diamond drill.

Assembly & Packaging (Back-End)



Individual die are put in a plastic or ceramic package. Tiny wire bonding is used to connect the chip. Testing is performed afterwards, usually in-house.

Moore's Law



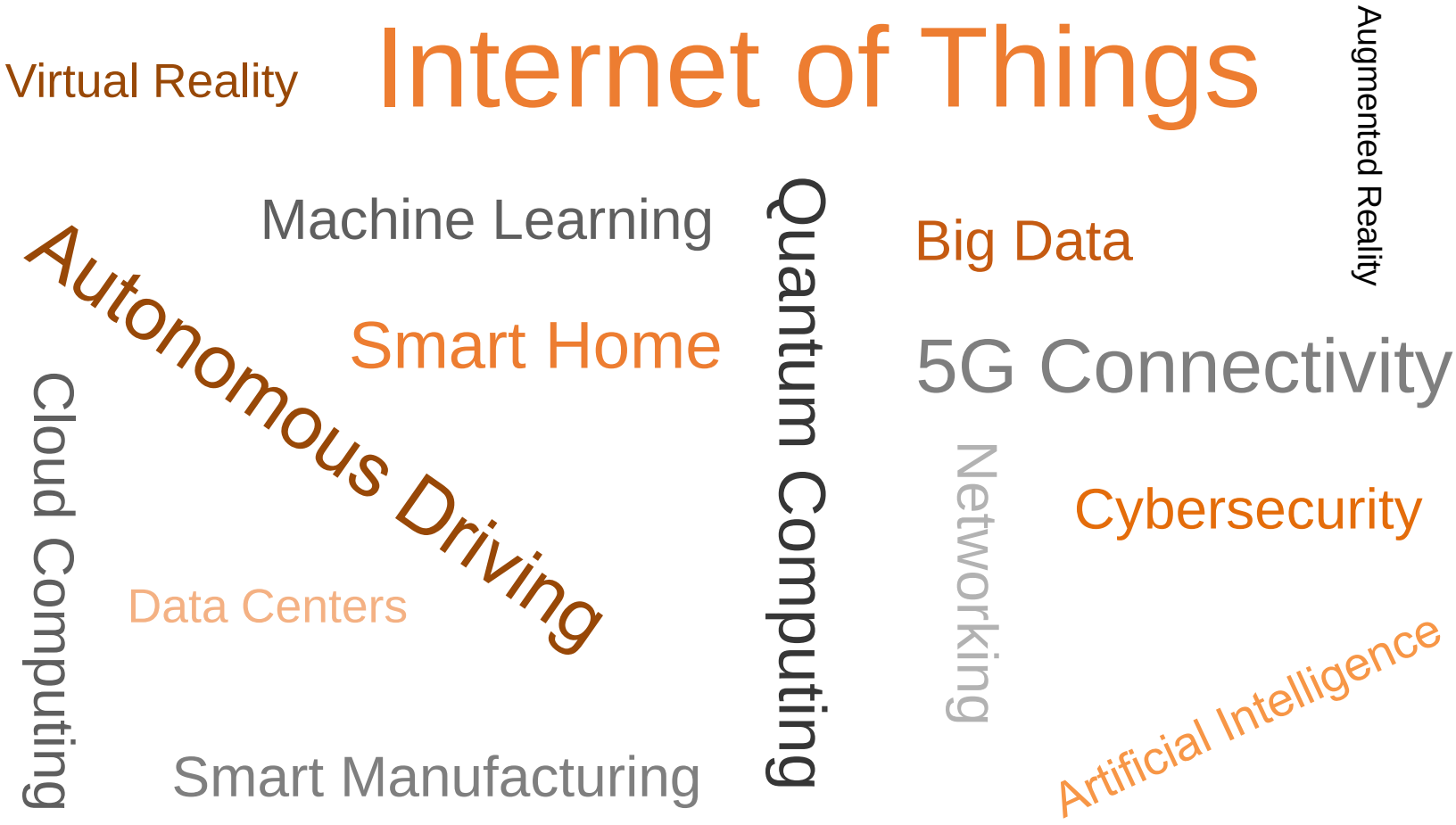
- **Moore's Law** states that the number of transistors on a chip doubles roughly every two years
  - Driven by advancements towards finer **lithography**[1]
- Smaller transistors enable:
  - Quicker electron movement → **Faster** devices
  - Smaller die sizes → **Cheaper** devices
  - Less electricity → **Lower power** consumption
- Physical limits on shrinking transistor size have sparked debate on whether the Law will continue to hold true

Sources: ST Micro, Wall Street Research

1. Lithography refers to the level of "smallness" the manufacturing process can achieve, which determines the size of the transistors on the die

Implications of Semis on Emerging Technologies

Lots of Buzzwords



Implications of Semis on Emerging Technologies (cont'd)

A Deeper Look into the Internet of Things: Overview of Connectivity Protocols

- **IoT protocols / standards** define the rules and formats that devices use for managing networks and transmitting data
- Features such as **data rates, coverage, capacity, battery life and module prices** determine the applications that a protocol is best suited for
- **International standard-setting organizations** such as the ISO[1] and IEC[2] are increasingly collaborating to address **fragmentation** across IoT standards, which has made it difficult for IoT developers and customers to decide on their partners
- Meanwhile, **telecom operators** around the world are commercializing LTE-based IoT networks to support their enterprise customers, with a focus on **NB-IoT** (narrow band IoT) and **eMTC** (enhanced Machine Type Connection) – these are both **3GPP**[3] standards
- There are also protocols such as **LoRa** and **Sigfox** which use **unlicensed spectrum** – these alternatives are more cost-friendly but are likely to experience greater **signal interference**, and lack the benefits of the rich **3GPP** ecosystem
- **Semiconductor companies** play a key role in developing chipset solutions that help facilitate connectivity; these firms also have various **different outlooks** on which IoT protocols will succeed, increasing the **prospects of M&A**

	Short-Range Connectivity Local Area Network (LAN)			*Long-Range Connectivity* Low Power Wide Area Network (LPWAN)					*Cellular Networks* Mobile Internet	
Specs Comparison	**Wi-Fi 802.11 Series**	**Bluetooth**	**ZigBee**	**NB-IoT (LTE Cat-NB1)**	**eMTC (LTE Cat-M1)**	**LTE Cat-1**	**LoRa**	**Sigfox**	**2G**	**3G/4G**
Transmission Rate	54 Mbps	1 Mbps	250 Kbps	50 Kbps	500 Kbps	10 Mbps	38 Kbps	<600 bps	90 Kbps	10 Mbps
Coverage Range	50m	10m	50-300m	---------- Several kilometers ----------					----- Several kilometers -----	
Network Capacity (# Nodes)	50	8	65k	100k	<100k	-	-	-	>100	>1000
Battery Life	Few hours	Few days	2 years	5-10 years	5-10 years	5 years	>10 years	>10 years	Few days	Few hours
Module Price (US$)	$25	$1	$5	$5	$10	$15	$8	$9	>$5	>$30
Use Licensed Spectrum	-	-	-	Yes	Yes	Yes	No	No	-	-
Common Applications	Internet access, multimedia, voice and video communication	Smartphones, connected home	Connected home, building automation, medical data collection	Wearables, smart meters, asset tracking, industrial sensors	Wearables, vending machines	Smartphones, surveillance cameras, drones	Command and control appplications (smart grid monitoring)	One-way data transfers (alarms, smart meters)	Voice communication, text messaging	Internet access, multimedia, voice and video communication

Sources: 3GPP, Business Wire, Gartner, GSMA, IBM, Link Labs, Qualcomm, Sigfox, u-blox, Wall Street Research

1. International Organization for Standardization
2. International Electro-technical Commission
3. The 3rd Generation Partnership Project unites 7 telecom standard development organizations

Implications of Semis on Emerging Technologies (cont'd)

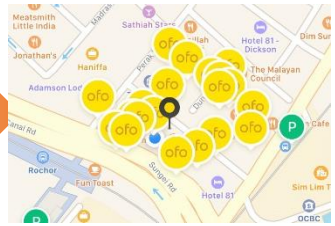
Select Key Vendors by Connectivity Standard

Short-Range Connectivity Local Area Network (LAN)			*Long-Range Connectivity* Low Power Wide Area Network (LPWAN)					*Cellular Networks* Mobile Internet	
Wi-Fi 802.11 Series	Bluetooth	ZigBee	NB-IoT (LTE Cat-NB1)	eMTC (LTE Cat-M1)	LTE Cat-1	LoRa	Sigfox	2G	3G/4G
Broadcom, Huawei, Intel, Qualcomm	Apple, Broadcom, Qualcomm, Samsung	NXP, Renesas, Silicon Labs, ST Microelectronics	Huawei, Qualcomm, u-blox, ZTE	MultiTech, Qualcomm, Sequans, u-blox	gemalto, Sequans, Sierra Wireless, u-blox	IBM, Semtech, ST Microelectronics, ZTE	Microchip, NXP, Silicon Labs, ST Microelectronics	-	Intel, Qualcomm, Samsung, u-blox

Ofo Bike Sharing: An Example of NB-IoT at Work

NB-IoT Enabled Bike Lock System

ofo



Track Down Location of Nearby Vacant Bikes on Mobile App

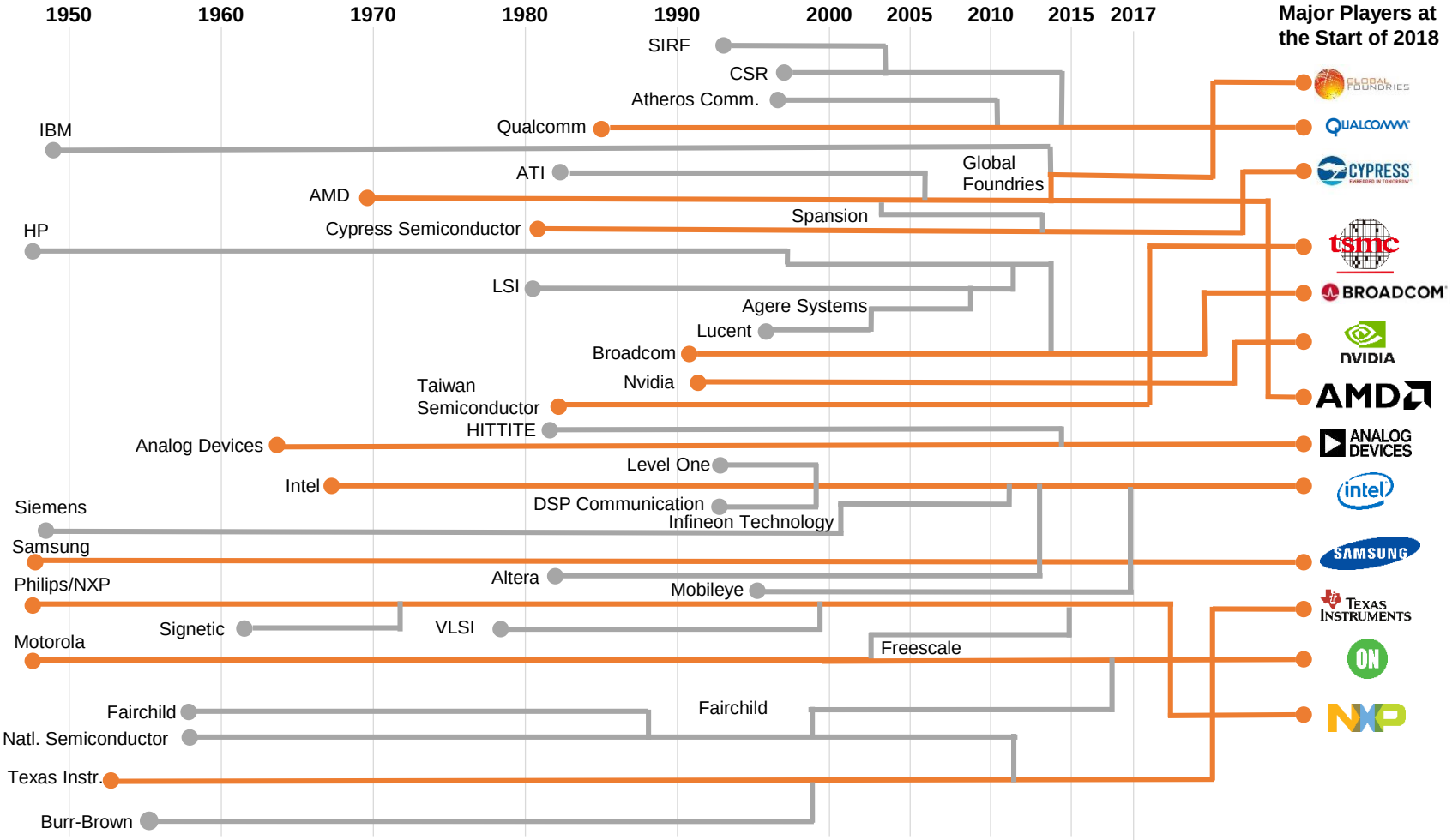
Connectivity in Our Pockets: The Evolution of iPhone Specs

iPhone 1	*iPhone 4*	*iPhone 6*	*iPhone XS*
			
802.11 b/g Bluetooth 2.0	802.11b/g/n Wi-Fi Bluetooth 2.1	802.11a/b/g/n/ac Wi-Fi Bluetooth 4.2	802.11ac Wi-Fi with 2x2 MIMO Bluetooth 5.0

Sources: Company Websites, Gartner, Wall Street Research

Semiconductor Industry M&A

History of Industry Consolidation: M&A Activity since 1950



Sources: Capital IQ, Fortune.com

Semiconductor Industry M&A (cont'd)

Notable Semiconductor M&A Transactions in 2018

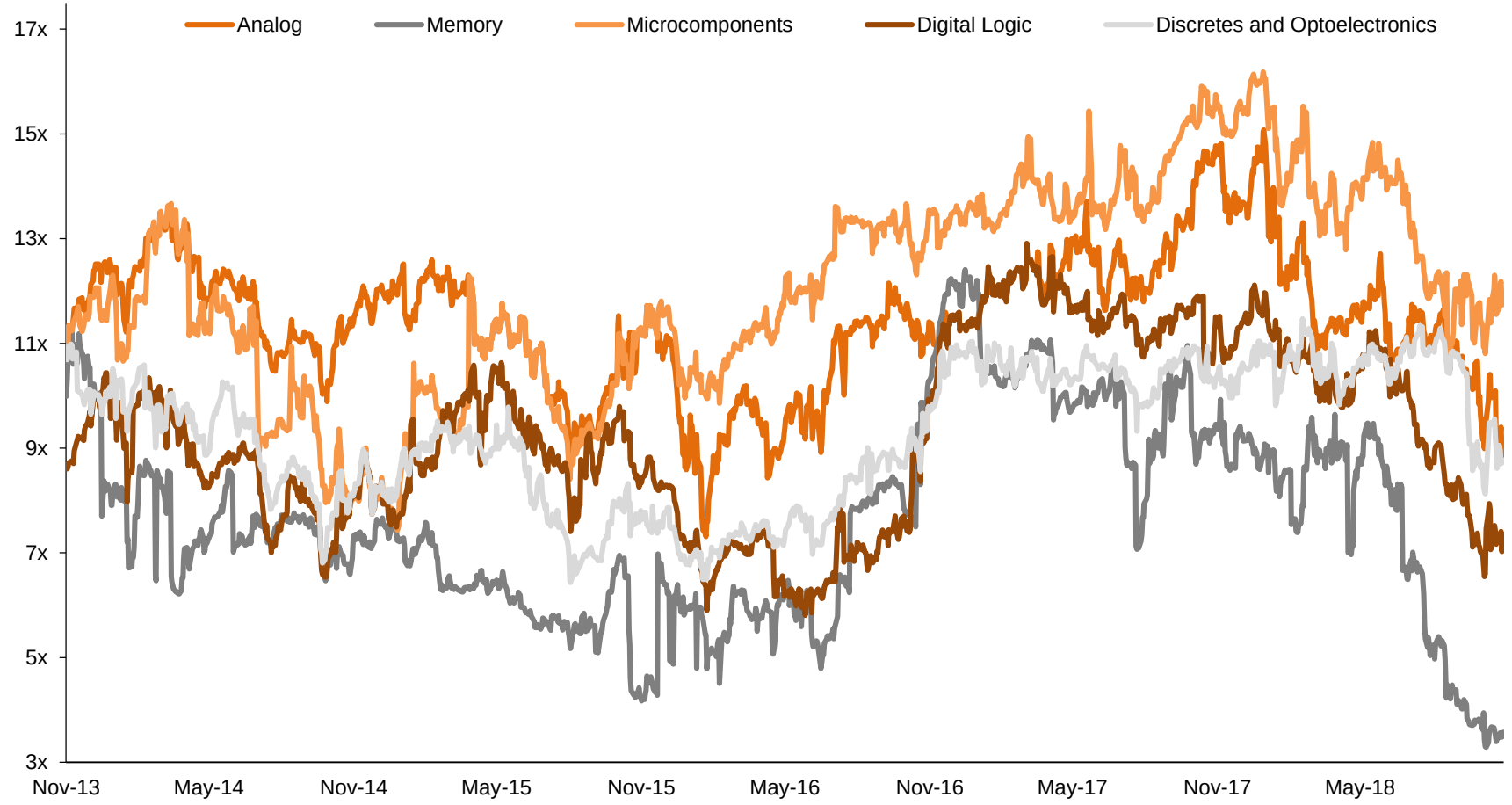
Date	Acquirer	Target	Type	Size (EV)	Multiple	Premium
09/10/2018	RENESAS	IDT Integrated Device Technology	Cash	$7.2bn	33.7x EV/EBITDA	15%
07/06/2018	MARVELL®	CAVIUM	Cash	$6.7bn	37.1x EV/EBITDA	11%
10/25/2018	Wing-Tech	nexperia	Cash	$2.6bn	nm	nm
01/30/2018	GigaDevice	Silead	Stock	$423mm	nm	nm
09/10/2018	KAGA ELECTRONICS	FUJITSU	Cash	$183mm	7.8x EV/EBIT	nm

Source: Capital IQ, Transaction Announcements

Semiconductor Multiple Movements

Semiconductor EV/EBITDA Multiples Over the Past 5 Years

EV/EBITDA multiples have generally followed industry boom and bust cycles, and have recently experienced a drop-off due to a decline in Chinese demand and price decreases driven by more firms entering the market and increasing competition.

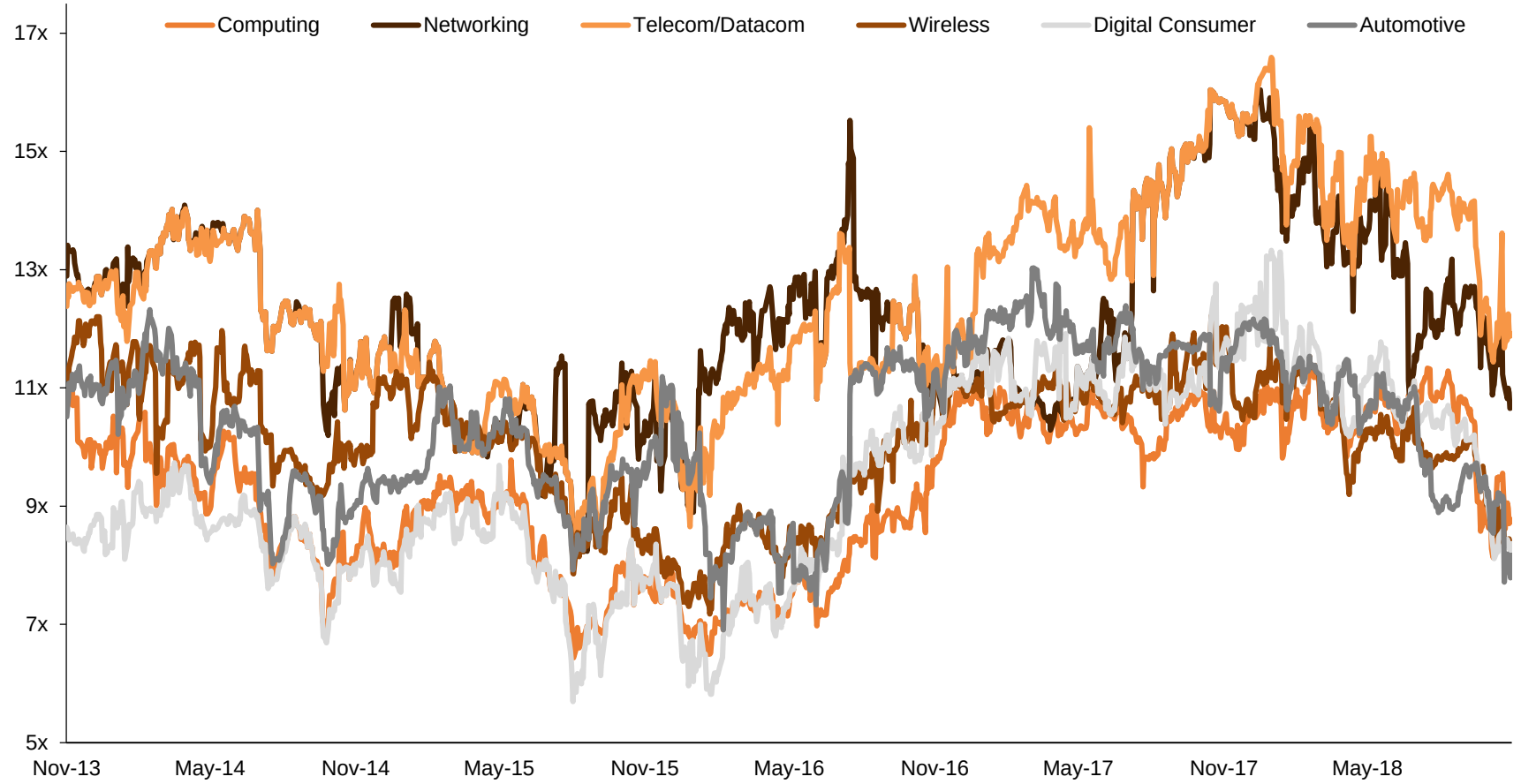


Sources: Capital IQ, Wall Street Research

Semiconductor Multiple Movements (cont'd)

End Market EV/EBITDA Multiples Over the Past 5 Years

Although semiconductor demand has increased over time, multiples for end market have remained relatively consistent for the past 5 years.



Sources: Capital IQ, Wall Street Research