

Lecture 9

Mobile Devices

Mobile Business I (WS 2023/24)

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[Source: Nokia]

- Introduction
- Categorisation of Mobile Devices
- Components of Mobile Devices
 - Accumulators
 - Processors, Memory, and Storage
 - Display
 - Means for I/O

- *A Mobile Device* is a small, handheld computing device.
- *Mobile Terminal* emphasises the fact that the mobile device represents the end of a communications link or the edge node of a communications network.

Device Manufacturers and Brands (including some historic ones)

- Alcatel
- Apple
- Audiovox
- Benefon
- BenQ Mobile
- Blackberry
- Bosch
- Ericsson
- Google
- HTC
- Huawei
- LG Electronics
- Microsoft
- Motorola
- NEC
- Nokia
- Panasonic



- Philips
- Sagem
- Samsung
- Sendo
- Siemens
- Sony
- TCL Communication
- Telepong
- Telit
- Telme
- Toshiba
- Trium
- Windhorst
- Xelibri
- Yulong
- ZTE

Company	1Q17 units	1Q17 Market Share (%)	1Q05 units	1Q05 Market		
Samsung	78,671.4	20.7	24,479.8	13.5		
Apple	51,992.5	13.7	-	-		
Huawei	34,181.2	9.0	-	-		
Oppo	30,922.3	8.1	-	-		
Vivo	25,842.2	6.8	-	-		
Nokia	↻ others		76,088.4	30.4		
LG Electronics (former LG)			11,464.2	6.3		
Lenovo*/Motorola			30,143.3	16.7		
Huawei			↻ others			
TCL Communication			↻ others			
ZTE			↻ others			
BenQ Mobile			10,209.5	5.7		
Sony Mobile Com.			9,905.8	5.5		
Others			158,368.7	41.7	39,829.5	21.9
TOTAL			379,977.3	100.0	180,992.2	100.0

Worldwide Mobile Phone Sales to End Users by Vendor Q1-2017 vs. Q1-2016

In 1.000 Units

Company	1Q17 Units	1Q17 Market Share (%)	1Q16 Units	1Q16 Market Share (%)
Samsung	78,671.4	20.7	81,186.9	23.2
Apple	51,992.5	13.7	51,629.5	14.8
Huawei	34,181.2	9.0	28,861.0	8.3
Oppo	30,922.3	8.1	16,112.6	4.6
Others	184,210.9	48.5	171,461.4	49.1
Total	379,978.3	100.0	349,251.4	100.0

Based on [Gartner2017]

Worldwide Mobile Phone Sales to End Users by Vendor 2012 vs. 2011 - A Decline?

In 1.000 Units

Company	2012 Units	2012 Market Share (%)	2011 Units	2011 Market Share (%)
Samsung	384,631.2	22.0	315,052.2	17.7
Nokia	333,938.0	19.1	422,478.3	23.8
Apple	130,133.2	7.5	89,263.2	5.0
ZTE	67,344.4	3.9	56,881.8	3.2
LG Electronics	58,015.9	3.3	86,370.9	4.9
Huawei Technologies	47,288.3	2.7	40,663.4	2.3
TCL Communication	37,176.6	2.1	34,037.5	1.9
Research In Motion	34,210.3	2.0	51,541.9	2.9
Motorola	33,916.3	1.9	40,269.1	2.3
HTC	32,121.8	1.8	43,266.9	2.4
Others	587399.6	33.6	595886.9	33.6
TOTAL	1,746,175.6	100.0	1,775,712.0	100.0

Cf. TOTAL Units sold in 2013: 1,820,200.0

[Statista2014]

[Gartner2013a]

In 1.000 Units

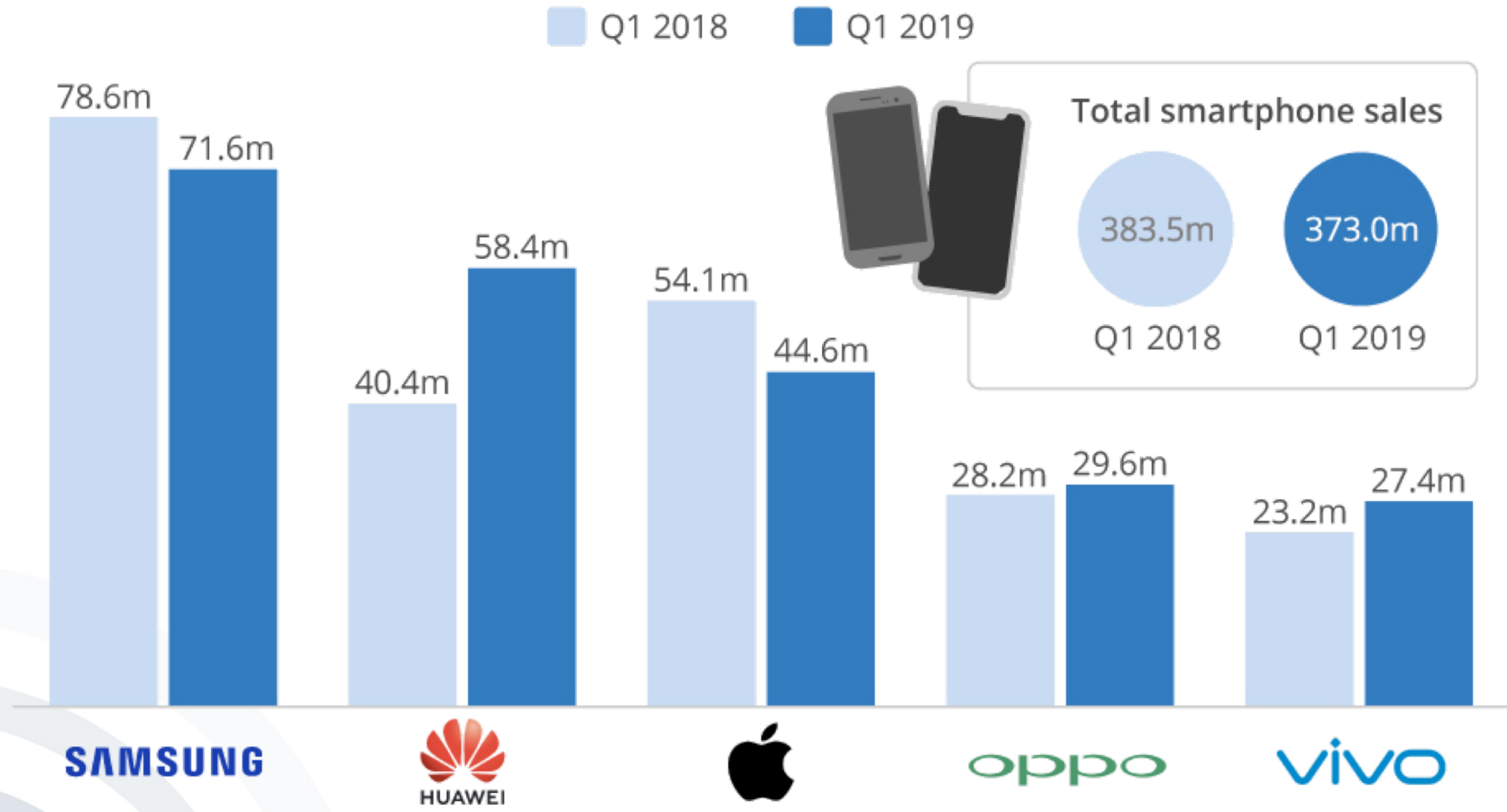
Company	1Q19	1Q19 Market Share (%)	4Q18	4Q18 Market Share (%)
	Units		Units	
Samsung	71,621.1	19.2	70,782.5	17.3
Huawei	58,436.2	15.7	60,409.8	14.8
Apple	44,568.6	11.9	64,527.8	15.8
Oppo	29,602.1	7.9	31,589.9	7.7
Others	141,405.2	45.2	153,205.0	44.3
Total	373,001.4	100%	408,358.5	100%

Based on [Gartner2019] and [Gartner2018]

- “Smartphones accounted for 51.8 percent of mobile phone sales in the second quarter of 2013, resulting in smartphone sales surpassing feature phone sales for the first time.”

[Gartner2013b]

Worldwide Smartphone Sales to End Users
by Vendor
Q1-2019 vs. Q1-2018



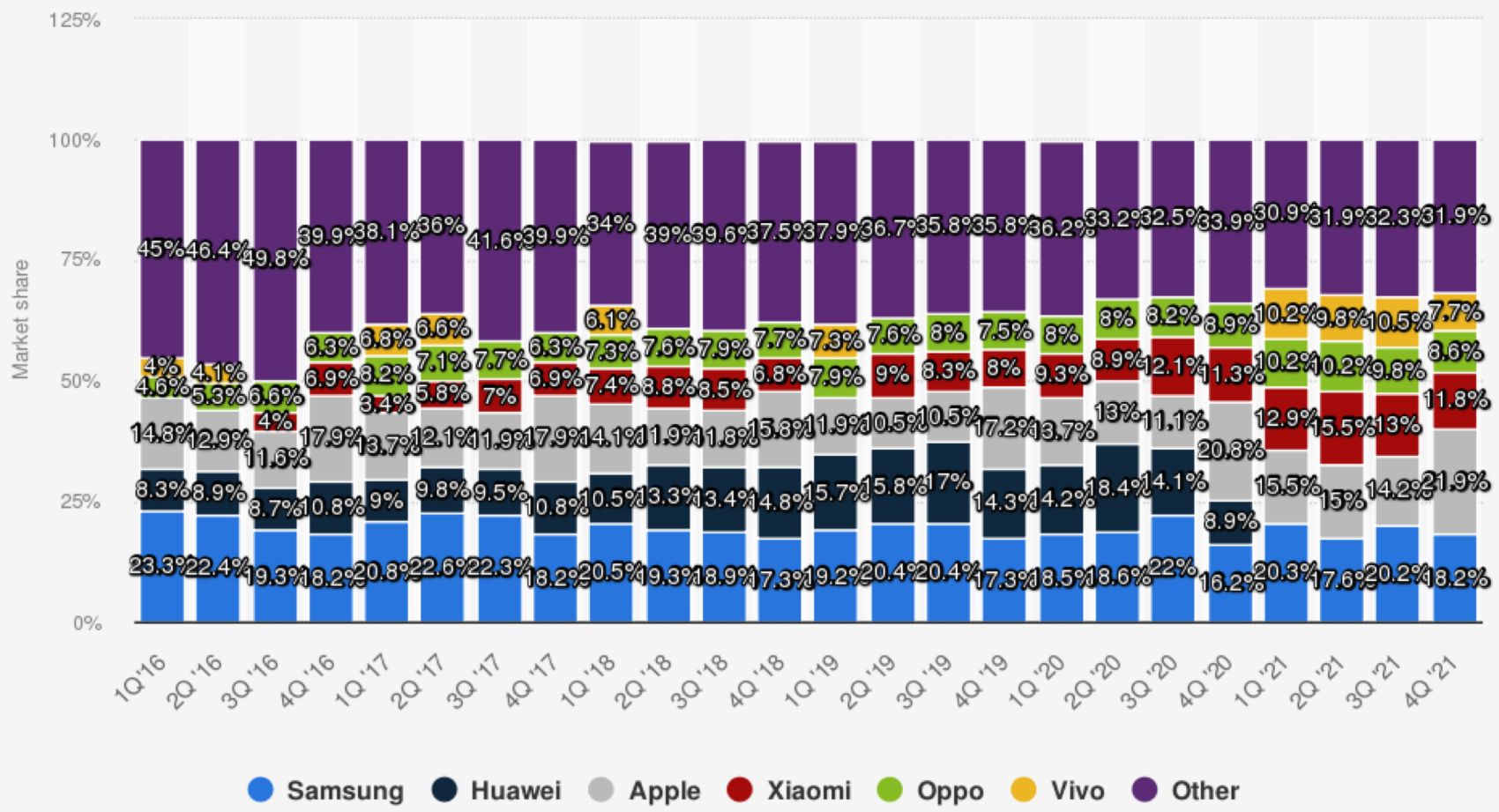
Worldwide Smartphone Sales to End Users by Vendor Q1-2019 vs. Q1-2018

In 1.000 Units

Company	1Q19 Units	1Q19 Market Share (%)	1Q18 Units	1Q18 Market Share (%)
Samsung	71,621.1	19.2	78,564.8	20.5
Huawei	58,436.2	15.7	40,426.7	10.5
Apple	44,568.6	11.9	54,058.9	14.1
Oppo	29,602.1	7.9	28,173.1	7.3
Vivo	27,368.2	7.3	23,243.2	6.1
Others	141,405.2	37.9	159,037.1	41.5
Total	373,001.4	100.0	383,503.9	100.0

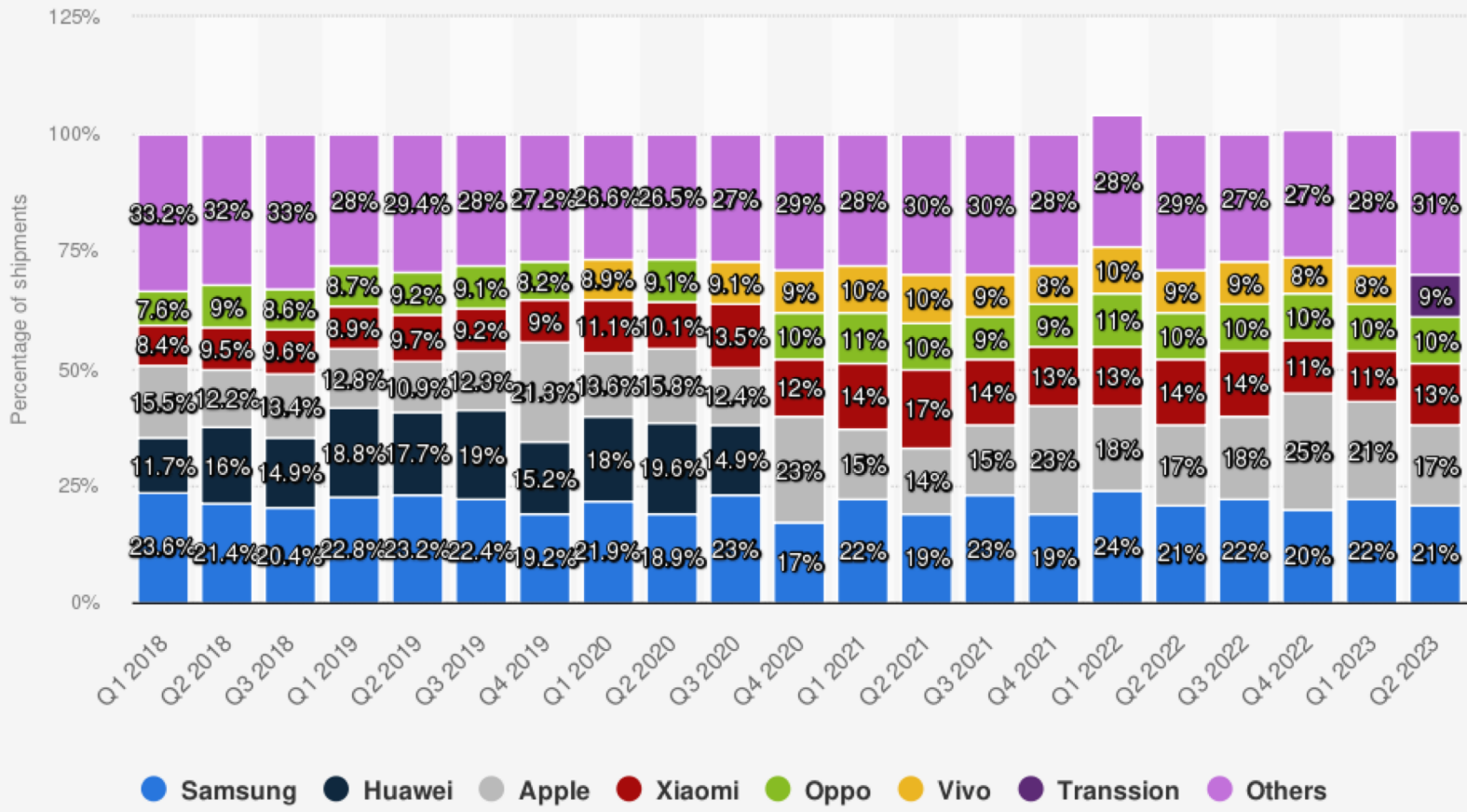
Source: [Gartner2019]

Worldwide Smartphone Sales to End Users by Vendor from Q1-2016 to Q4-2021



Source: Gartner © Statista 2022

Additional Information: Worldwide; 2016 to 2021

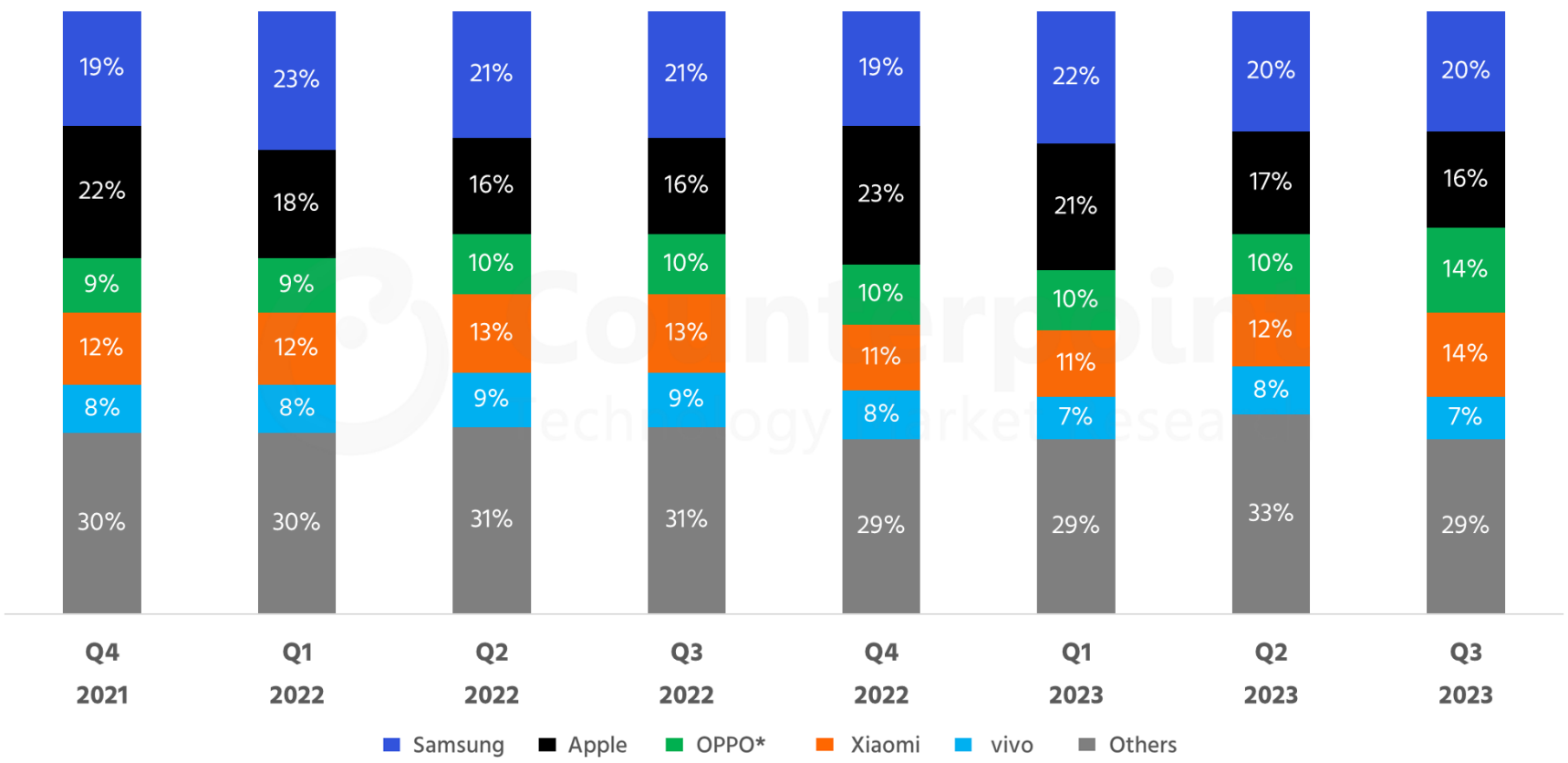


Source
Canalys
© Statista 2023

Additional Information:
Worldwide; 2018 to 2023



Global Smartphone Market Share (Q4 2021 – Q3 2023)



* OPPO includes OnePlus since Q3 2021

Worldwide Smartphone Market Share % by Vendor from Q4-2021 to Q3-2023

Brands	Q4 2021	Q1 2022	Q2 2022	Q3 2022	Q4 2022	Q1 2023	Q2 2023	Q3 2023
Samsung	19%	23%	21%	21%	19%	22%	20%	20%
Apple	22%	18%	16%	16%	23%	21%	17%	16%
OPPO*	9%	9%	10%	10%	10%	10%	10%	14%
Xiaomi	12%	12%	13%	13%	11%	11%	12%	14%
vivo	8%	8%	9%	9%	8%	7%	8%	7%
Others	30%	30%	31%	31%	29%	29%	33%	29%

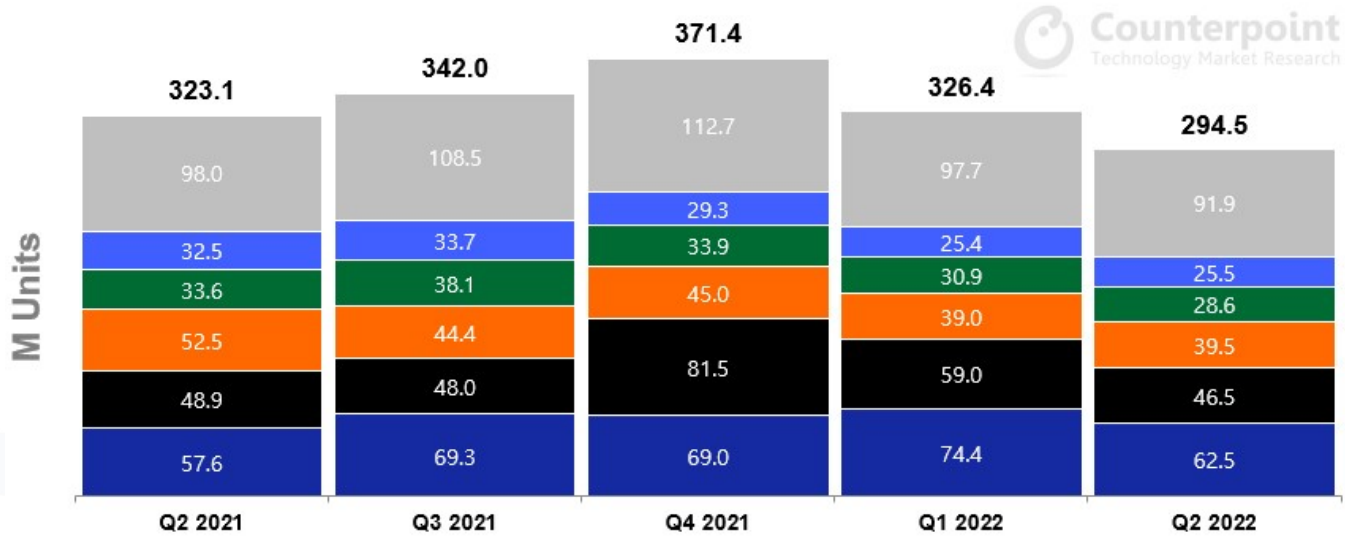
Worldwide Smartphone Shipments by Vendor from Q4-2021 to Q3-2023

(in Millions)

Brands	Q4 2021	Q1 2022	Q2 2022	Q3 2022	Q4 2022	Q1 2023	Q2 2023	Q3 2023
Samsung	69	74.5	62.5	64.3	58.3	60.6	53.5	59.4
Apple	81.5	59	46.5	49.2	70	58	45.3	48.9
OPPO*	33.9	30.9	28.2	29.5	29.6	28.4	28	42.1
Xiaomi	45	39	39.5	40.5	33.2	30.5	33.2	41.5
vivo	29.3	24.8	25.5	26	23.4	20.8	21.4	22.1
Others	112.7	98.1	92.3	92.4	89.4	81.9	86.6	85.8
Total	371.4	326.4	294.5	301.9	303.9	280.2	268	299.8

[counterpointresearch2023]

Quarterly Global Smartphone Shipments by Key OEM

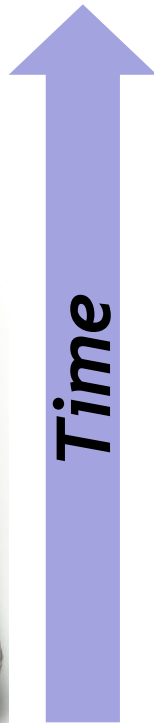


Q2 2022 Vs Q2 2021
YoY % Change

Total	-9%
Others	-6%
vivo	-22%
oppo	-15%
mi	-25%
Apple	-5%
SAMSUNG	+9%

Source: Counterpoint Research Quarterly Market Monitor, Q2 2022
Note: OPPO includes OnePlus since Q3 2021

Evolution of Mobile Devices, Development of the Capabilities



- Augmented Reality (AR) capabilities
- Near Field Communication (NFC)
- Sensors (accelerometer, gyroscope, etc.)
- Possibility to execute 3rd party software
- Multimedia applications (MP3, radio, camera, video, TV, etc.)
- Data services (GPRS, UMTS, LTE, Wi-Fi)
- Bluetooth
- Interactive Voice Response (IVR)
- Short Message Service (SMS)
- General telephony capabilities

Evolution of Mobile "Devices"

Examples



© New York Times

1973



© Microoptical

2001



2005



2006



2007



2010



2013



2016



2017



2019-2022



- Everybody wants smaller devices.
- Everybody ? ...



Worldwide Device Shipments by Segment - 2018 View

- Worldwide device shipments and projections by segment show a shift in consumer preferences:

Device Type	2016	2017	2018	2019
<i>Traditional PCs (Desk-Based and Notebook)</i>	220	204	193	187
<i>Ultramobiles (Premium)</i>	50	59	70	80
PC Market	270	262	264	267
<i>Ultramobiles (Tablets and Clamshells)</i>	169	160	159	156
Computing Devices Market	439	423	423	423
<i>Mobile Phones</i>	1,893	1,855	1,903	1,924
Total Devices Market	2,332	2,278	2,326	2,347

Note: The *Ultramobile (Premium)* category includes devices such as Microsoft's Windows 8 Intel x86 products and Apple's MacBook Air.

The *Ultramobile (Tablets and Clamshells)* category includes devices such as, iPad, iPad mini, Samsung Galaxy Tab S 10.5, Nexus 7 and Acer Iconia Tab 8.

- The reason may be an increasing focus on energy efficiency and weight.

Worldwide Device Shipments by Segment - 2019 View

In 1.000 Units

Device Type	2018	2019	2020	2021
<i>Traditional PCs (Desk-Based and Notebook)</i>	195,317	189,472	182,823	175,058
<i>Ultramobile (Premium)</i>	64,471	68,869	74,432	79,871
PC Market	259,787	258,341	257,255	254,929
<i>Ultramobiles (Basic and Utility)</i>	149,561	147,963	145,811	143,707
Computing Devices Market	409,348	406,304	403,066	398,636
<i>Mobile Phones</i>	1,811,922	1,802,628	1,824,628	1,798,356
TOTAL	2,221,270	2,208,697	2,227,694	2,196,992

- Note: The *Ultramobile (Premium)* category includes devices such as Microsoft's Windows 10 Intel x86 products and Apple's MacBook Air.
The *Ultramobile (Basic and Utility Tablets)* category includes devices such as, iPad, iPad mini, Samsung Galaxy Tab S2, Amazon Fire HD, Lenovo Yoga Tab 3, Acer Iconia One.

Worldwide Device Shipments by Segment - 2022 View

In 1,000 Units

Device Type	2020	2021	2022
<i>Traditional PCs (Desk-Based and Notebook)</i>	178.279	169.891	161.672
<i>Ultramobiles (Premium)</i>	72.529	76.789	80.036
Total PC Market	250.807	246.680	241.708
<i>Ultramobiles (Basic and Utility)</i>	138.712	134.255	132.465
Computing Device Market	389.519	380.935	374.173
<i>Mobile Phones</i>	1, 776.779	1, 771.242	1, 756.936
Total Market	2, 166.298	2, 152.177	2, 131.109

- Note: The *Ultramobile (Premium)* category includes devices such as Microsoft's Windows 10 Intel x86 products and Apple's MacBook Air. The *Ultramobile (Basic and Utility Tablets)* category includes devices such as, iPad, iPad mini, Samsung Galaxy Tab S2, Amazon Fire HD, Lenovo Yoga Tab 3, Acer Iconia One.

Worldwide Shipments Forecast by Device Type, 2022-2023

In 1.000 Units

Device Type	2022 Shipments	2022 Growth (%)	2023 Shipments	2023 Growth (%)
PC	287,159	-16.0	267,676	-6.8
Tablet	136,938	-12.0	132,963	-2.9
Mobile Phone	1,395,247	-11.0	1,339,505	-4.0
Total Devices	1,819,344	-11.9	1,740,143	-4.4

“Fair” and ecologically friendly Mobile Devices

- Grounded in the idea to develop and market smartphone hardware and software designed and produced with minimal harm to people and planet.
- Strict observation of:
 - Type of raw materials (ecological aspects)
 - Origin of raw materials (political aspects)
 - Lifespan of components and easy repair (durability aspects)
 - Upgradeable through modularization

FAIRPHONE



It is “not possible to produce a 100% fair phone yet, but by aiming toward this end seeks to raise awareness among consumers and in the mobile industry.” [Wiki2013]



[Source: news.phonebloks.com]

“Fair” and ecologically friendly Mobile Devices

- Fairphone 1 out of stock
 - 25,000 from the first batch of Fairphones sold in 2013.
 - 35,000 from the second batch of Fairphones on sale in 2014.
- Fairphone 2 [www.fairphone.com/about/]
 - Over 65,310 phones delivered by the end of 2017.
 - More available on the online shop and from some retail partners

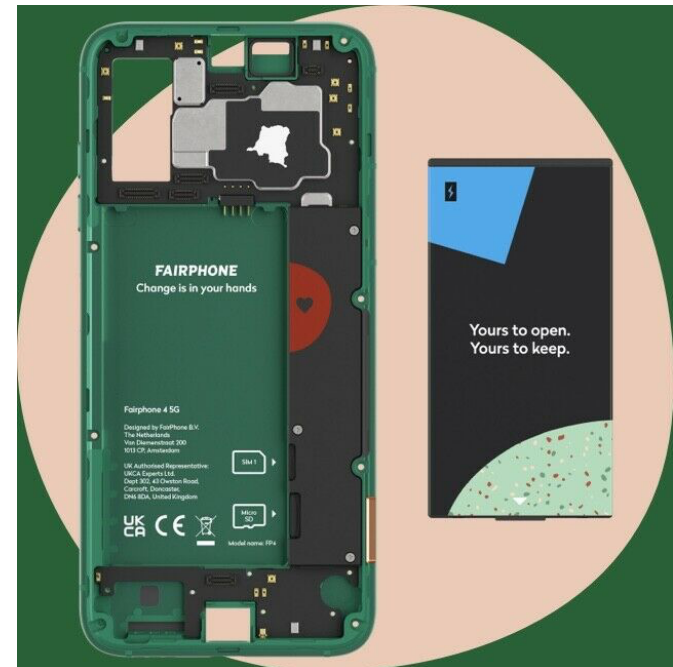
FAIRPHONE

[Fairphone2016, Fairphone2017]

Model	Release Date
Fairphone 1	Dec 2013
Fairphone 2	Dec 2015
Fairphone 3	Sep 2019
Fairphone 3+	Sep 2020
Fairphone 4	Sep 2021
Fairphone 5	Aug 2023

[Wiki2023]

[Fairphone2023]



- Introduction
- **Categorisation of Mobile Devices**
- Components of Mobile Devices
 - Accumulators
 - Processors, Memory, and Storage
 - Display
 - Means for I/O

- Categorisation is possible by:
 - Technical characteristics
 - Application aspects
 - Lifespan of an application
 - Functional completeness (Is the functionality comparable to a desktop PC/Laptop?)
 - Size of the device
 - Security features

- Hardware independence
 - Independent devices
 - Devices with external communication
 - Devices with external security modules
 - Devices with external memory

- Operating system – Characteristics
 - Memory security, file security, access control
 - Security module support, secure I/O, program and system integrity

- Lifespan of an application
 - Battery consumption, amount of data, and size of memory
 - Data integrity, amount of communication, and costs
- Completeness of the functionality for the end-user
 - Information / Reaction
 - Limitations due to device size
 - Feature Sets

- Device size
 - Small / integrated devices
 - „Pocket-sized“
 - „Tablet-sized“
 - „Laptop-sized“

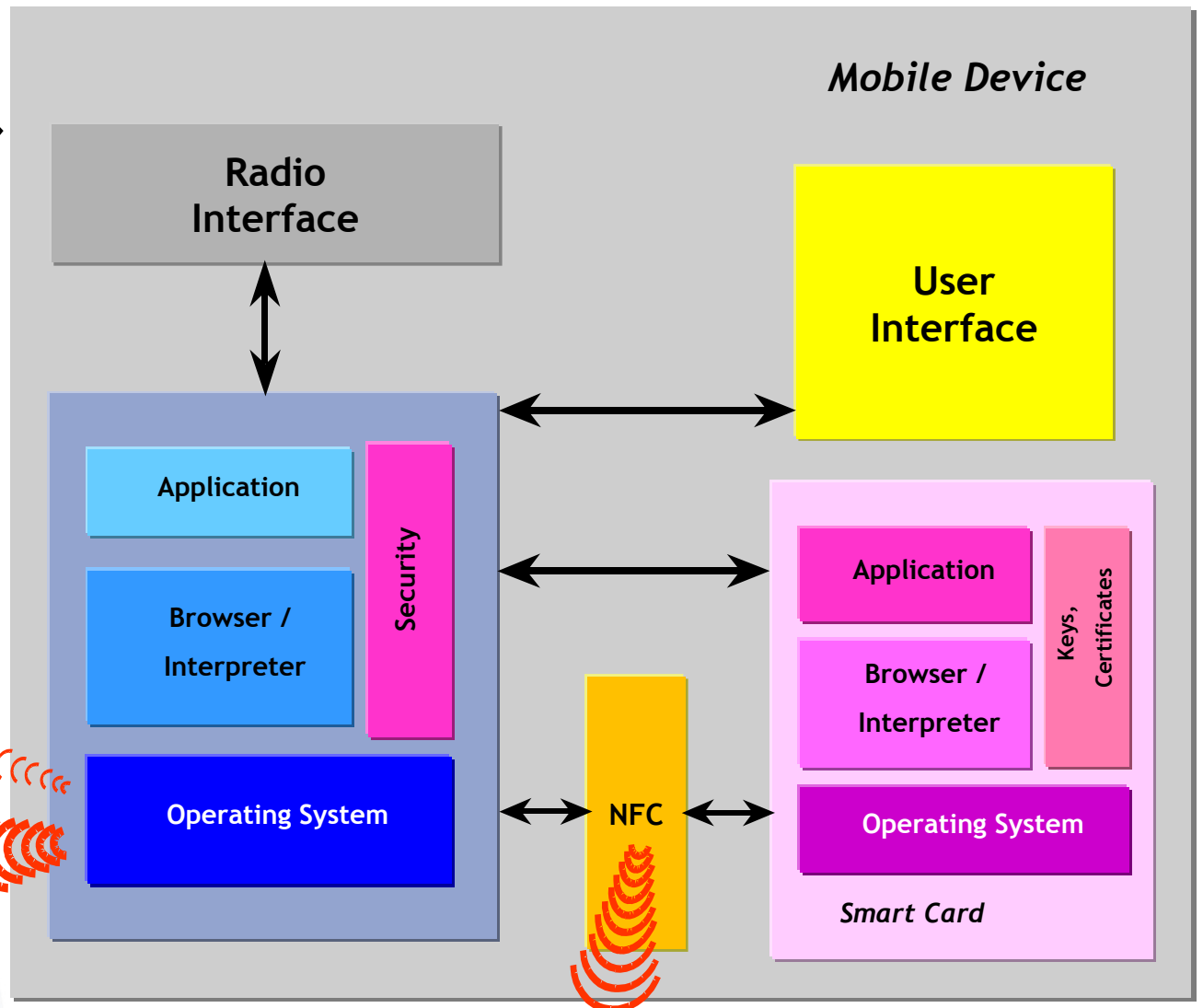
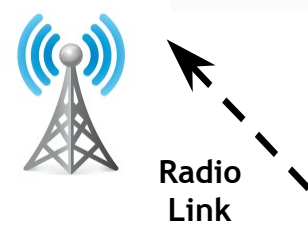
- Access to the security module
 - Data integrity, encryption
 - Digital signatures
 - Access control, authentication

- Different requirements for different kinds of devices:

	Mobile Phone	Tablet	Laptop
<i>Number of „Switch-ons“ per day</i>	low	low	variable
<i>Frequency of use cases</i>	very high	rather low	low
<i>Duration of usage per task</i>	variable	short/ medium	high

Based on [Burckhardt2001]

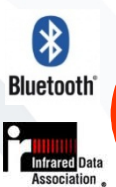
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Global Positioning System (GPS)








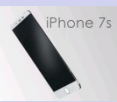






PAN: Bluetooth, Infrared, ...








- The size of a mobile device is considerably determined by its:
 - Input Facilities (e.g. keyboard)
 - Output Facilities (e.g. display)
- ➔ Separation of components (e.g. display in the watch, head-mounted-displays)

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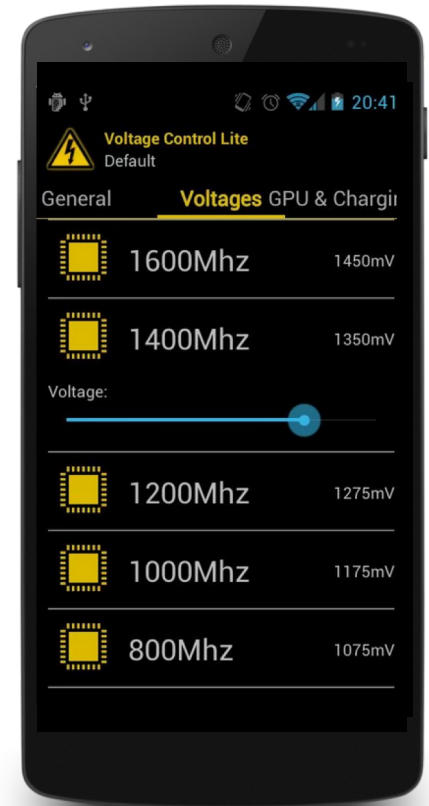
Mobile phone	Standby time (in h)	Talk time (in min)	Capacity (in mAh)	Display
Nokia 6310 (2001) 	408	360	Li-Polymer; 1.100 mAh	Graphic 96 x 65
Nokia N-Gage (2004) 	240	120	Li-Ion; 850 mAh	Color 176 x 208 4.096 colours
MDA pro (2005) 	260	480	Li-Polymer; 1.620 mAh	Touch TFT 640 x 480 65.536 colours
T-Mobile Ameo (2007) 	300	240	Li-Ion; 2200 mAh	Touch TFT 640 x 480 65.536 colours
Apple iPhone 4 (2010) 	300	420 (3G) - 840 (2G)	Li-Polymer; 1420 mAh	Touch TFT 960 x 640 16.7m colours
Apple iPad Air 2 (2014) 	<i>Up to 9 hours of surfing the web using 3G data network (10 hours with WiFi)</i>		Li-Polymer; 7,340 mAh	Touch TFT 2048 x 1536 16.7m colours
Apple iPhone 6S (2015) 	<i>Talk time: Up to 14 hours on 3G Internet use: Up to 10 hours on 3G, up to 10 hours on LTE, up to 11 hours on Wi-Fi</i>		Li-Polymer; 1,715 mAh	LED-backlit LCD, capacitive touchscreen, 16m colours
Apple iPhone 7 (2016) 	<i>Talk time: Up to 14 hours on 3G Internet use: Up to 12 hours on 3G/LTE, Up to 14 hours on Wi-Fi</i>		Li-Ion; 1960 mAh	4.7-inch (diagonal) LED-backlit widescreen, 1334 x 750

Mobile phone	Standby time (in h)	Talk time (in min)	Capacity (in mAh)	Display
Apple iPhone 8 (2017) 		<i>Talk time (wireless): Up to 14 hours</i> <i>Internet use: Up to 12 hours</i>	Li-Ion; 1,821 mAh	4.7-inch (diagonal) widescreen LCD Multi-Touch display with IPS technology 1334 x 750
Apple iPhone X (2017) 		<i>Talk time (wireless): Up to 21 hours</i> <i>Internet use: Up to 12 hours</i>	Li-Ion; 2,716 mAh	5.8-inch (diagonal) all-screen OLED Multi-Touch display HDR display 2436 x 1125
Apple iPhone XR (2018) 		<i>Talk time (wireless): Up to 25 hours</i> <i>Internet use: Up to 15 hours</i>	Li-Ion; 2942 mAh	6.1-inch (diagonal) all-screen LCD Multi-Touch display with IPS technology 1792 x 828
iPhone XS / XS Max (2018) 		<i>Talk time (wireless): Up to 25 hours</i> <i>Internet use: Up to 15 hours</i>	Li-Ion; 3174 mAh	6.5 inch Super Retina HD display 2688 x 1242









Mobile phone	Video Playback (in h)	Audio Playback (in h)	Capacity (in mAh)	Display
iPhone 11 / 11 Pro / 11 Pro Max (2019) 	<i>Video playback up to 20 hours, video playback (streamed) up to 12 hours, and audio playback up to 80 hours</i>		Li-Ion; 3969 mAh (Fast charge)	6.5 inch Super Retina XDR OLED display 2688 x 1242
iPhone 12 / 12 Pro / 12 Pro Max (2020) 	<i>Video playback up to 20 hours, video playback (streamed) up to 12 hours, and audio playback up to 80 hours</i>		Li-Ion; 3687 mAh (Fast charge)	6.7 inch Super Retina XDR OLED display 2778x1284
iPhone 13 / 13 Pro / 13 Pro Max (2021) 	<i>Video playback up to 28 hours, video playback (streamed) up to 25 hours, and audio playback up to 95 hours</i>		Li-Ion; 4352 mAh (Fast charge)	6.7 inch Super Retina XDR OLED display 2778x1284
iPhone 14 / 14 Pro / 14 Pro Max (2022) 	<i>Video playback up to 29 hours, video playback (streamed) up to 25 hours, and audio playback up to 95 hours</i>		Li-Ion; 3687 mAh (Fast charge)	6.7 inch LTPO Super Retina XDR OLED 2796x1290
iPhone 15 / 15 Plus / 15 Pro / 15 Pro Max (2023) 	<i>Video playback up to 29 hours, video playback (streamed) up to 25 hours, and audio playback up to 95 hours</i>		Li-Ion; 4441 mAh (Fast charge)	6.7 inch LTPO Super Retina XDR OLED 2796x1290




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- Performance increase
 - Higher clock frequency (but frequency scaling typically comes at the price of higher voltage!)
 - Larger on-die-caches (cache memory) built into the CPU (“on die”) to reduce memory access time
- Power consumption decrease
 - Processor's core voltage (1995: 3.5 V; 2000: 1.35 V; 2013: 1.0 V; **2022: 0.9-1.3V**)
 - Lower bound is the voltage needed to switch a transistor
 - Quadratic relationship between voltage and power consumption
- ➡ Less heat loss
- Power Management
 - triggered by changes of the energy supply



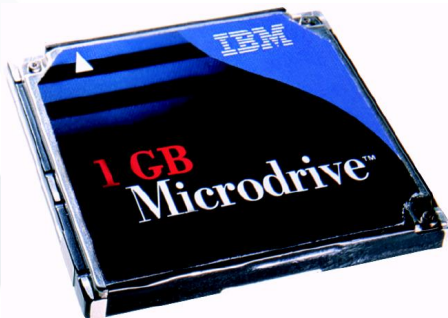
Picture source: “Voltage Control” Application (Google Play Store) by darek.xan

Logo	Device	Processor	Mhz	MIPS
	Nokia N-Gage (2004)	ARM7	104	??
	HTC/T-Mobile MDA (2002)	Intel StrongARM	206	274
	Apple iPhone 4, iPad (2010)	Apple A4	800 (iPad: 1000)	2.000
	Notebook (2006)	Intel CoreDuo Processor	2.000	< 14.000
	Notebook (2010)	Intel Core i7 Quad-Core	3.600	> 20.000
	Apple iPad Air 2 (2014)	Apple A8X	1.500 (Triple-core)	??
	Apple iPhone 6S (2015)	Apple A9	1,800 (Dual-core)	??
	Apple iPhone 7 (2017)	Apple A10	2,300 (Quad-core)	??

Logo	Device	Processor	Mhz	MIPS
	Apple iPhone 8 (2017)	Apple A11 Bionic	2,39 (Hexa-core)	??
	Apple iPhone X (2017)	Apple A11 Bionic	2,39 (Hexa-core)	??
	Apple iPhone XR (2018)	Apple A4	2,49 (Hexa-core)	??

Logo	Device	Processor	Mhz	MIPS
	iPhone 11 / 11 Pro / 11 Pro Max (2019)	Apple A13 Bionic (7 nm+)	Hexa-core (2x2.65 GHz Lightning + 4x1.8 GHz Thunder)	
	iPhone 12 / 12 Pro / 12 Pro Max (2020)	Apple A14 Bionic (5 nm)	Hexa-core (2x3.1 GHz Firestorm + 4x1.8 GHz Icestorm)	
	iPhone 13 / 13 Pro / 13 Pro Max (2021)	Apple A15 Bionic (5 nm)	Hexa-core (2x3.23 GHz Avalanche + 4x1.82 GHz Blizzard)	
	iPhone 14 / 14 Pro / 14 Pro Max (2022)	Apple A16 Bionic (4 nm)	Hexa-core (2x3.46 GHz Everest + 4x2.02 GHz Sawtooth)	
	iPhone 15 / 15 Plus / 15 Pro / 15 Pro Max (2023)	Apple A17 Pro (3 nm)	Hexa-core (2x3.78 GHz Everest + 4x2.11 GHz Sawtooth)	

- General trade-off between storage on the server vs. storage on the client
- Storage on the client
 - Subscriber Identity Module (SIM)
 - Random Access Memory (RAM)
 - Memory cards
 - Microdrives



- Introduction
- Categorisation of Mobile Devices
- Components of Mobile Devices
 - Accumulators
 - Processors, Memory, and Storage
 - Display
 - Liquid-Crystal-Displays (LCD)
 - Organic Light Emitting Diodes (OLED)
 - Means for I/O













- The LCD technology is widespread in the market.
- “Consists of an array of tiny segments (called pixels) that can be manipulated to present information“
- Examples:
 - Dual Scan Twisted Nematic (DSTN)
 - Thin-film Transistor (TFT)





Example: Dynasheet (Toshiba)
1cm, 200g, 2005

- DSTN-Display (Dual Scan Twisted Nematic)
 - Passive matrix
 - LCD displays with passive control have a relatively high latency (generally more than 100 ms). This implies a blurred image with frequently changing picture elements.

- TFT-Displays (Thin Film Transistor)
 - Active (transistor for each pixel)

Logo	Mobile phone	Display	Resolution	Colours
	Nokia 6310 (2001)	Graphic	96 x 65	none
	Siemens S55 (2002)	Color	101 x 80	256
	Nokia N-Gage (2004)	Color	176 x 208	4.096
	Samsung E700 (2003)	TFT-Color	160 x 128	65.536
	MDA III (2004)	Touch TFT	320 x 240	65.536
	MDA Pro (2005)	Touch TFT	640 x 480	65.536
	T-Mobile Ameo (2007)	Touch TFT	640 x 480	65.536
	Apple iPhone 4 (2010)	Touch TFT	960 x 640	16.7m
	Apple iPad 2 (2010)	Touch TFT	1024 x 768	16.7m
	Apple iPad 3 (2012)	Touch TFT	2048 x 1536	16.7m
	Apple iPad Pro (2015)	Touch TFT	2732 x 2048	16.7m
	Apple iPad Pro 2 (2017)	Touch TFT	2732 x 2048	16.7m

Logo	Mobile phone	Display	Resolution	Colours
	Apple iPhone X (2017)	AMOLED	2436 x 1125	??
	Samsung Galaxy S10 (2019)	AMOLED	3040 x 1440	??
	iPhone 11 / 11 Pro / 11 Pro Max (2019)	Super Retina XDR OLED	2688 x 1242	
	iPhone 12 / 12 Pro / 12 Pro Max (2020)	Super Retina XDR OLED	2778 x 1284	
	iPhone 13 / 13 Pro / 13 Pro Max (2021)	Super Retina XDR OLED	2778 x 1284	
	iPhone 14, 15 / 14, 15 Plus & Pro / 14, 15 Pro Max (2022, 2023)	LTPO Super Retina XDR OLED	2796 x 1290	

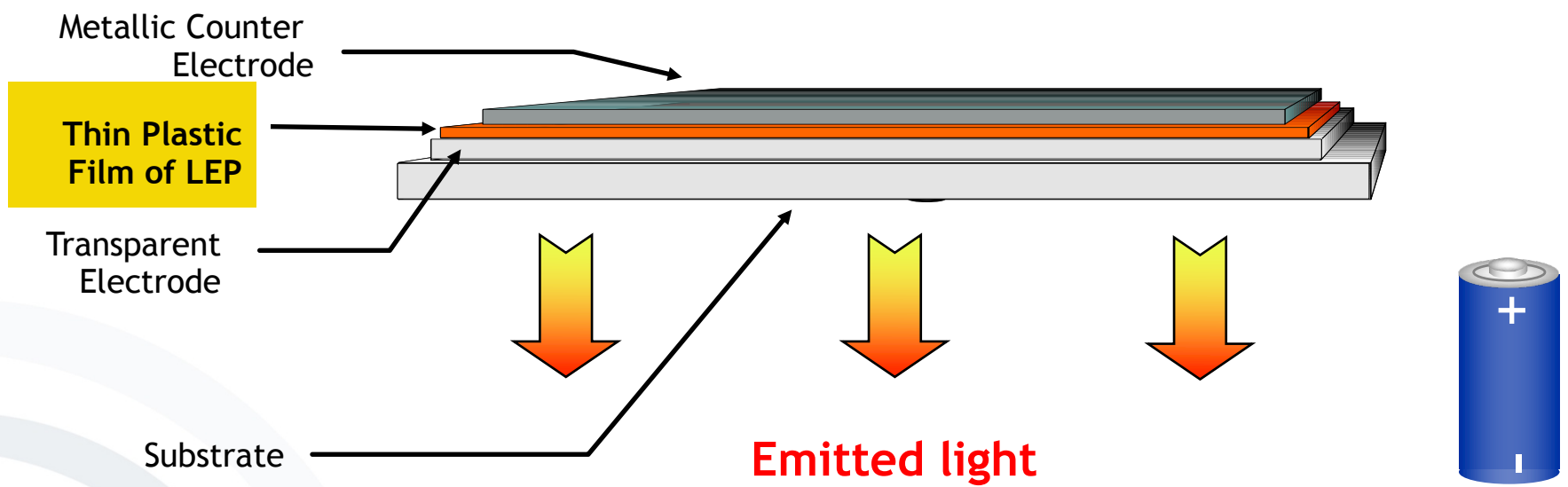
Organic Light Emitting Diodes (OLED)

- Polymers can convert electric energy to light.
- Complete layer is thinner than 500 nm (0.5 thousandth part of one mm), luminosity approx. 100W electric bulb.
- 180° viewing angle



- OLED consist of self lighting polymer molecules:
 - No background lighting is necessary
 - Electric power consumption decreases and longer usage times become possible.
 - Space for extra components
 - Devices can be thinner and lighter.

Light Emitting Polymer Device



- Polymers are large molecules widely known as plastics.
- *Light Emitting Polymers (LEPs)* are special plastic materials that convert electrical power into visible light.
- A thin film of *Light Emitting Polymer* put between two electrodes will glow ...

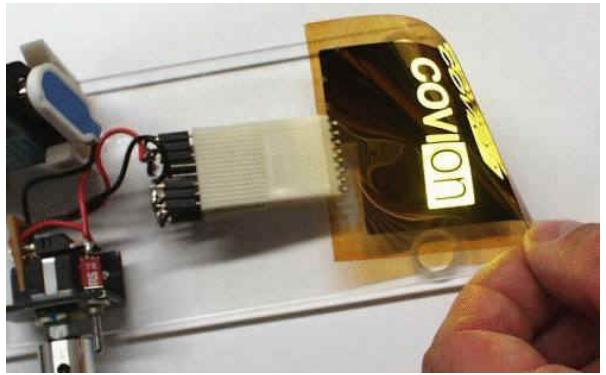
Light Emitting Polymers convert electrical power into visible light:



This is related to the fluorescence of polymers where UV-radiation is converted into visible light:

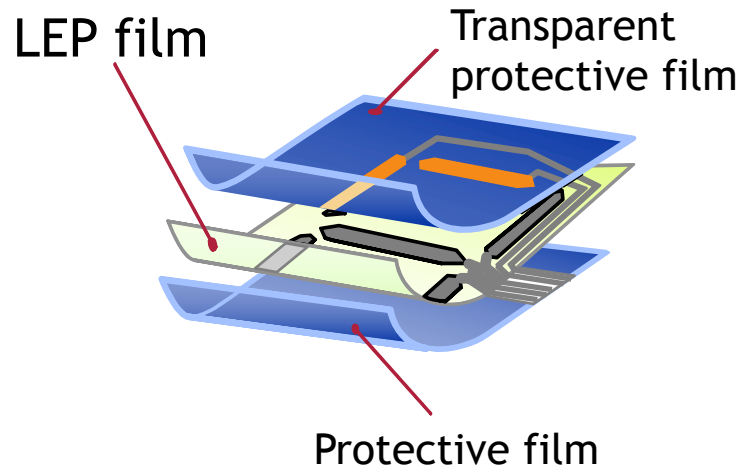


- Because plastic materials are flexible and robust even non-planar displays can be manufactured ...



Samsung Galaxy Round (2013 in Korea)

[Samsung2013]

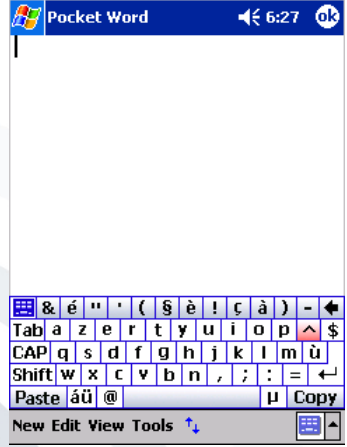
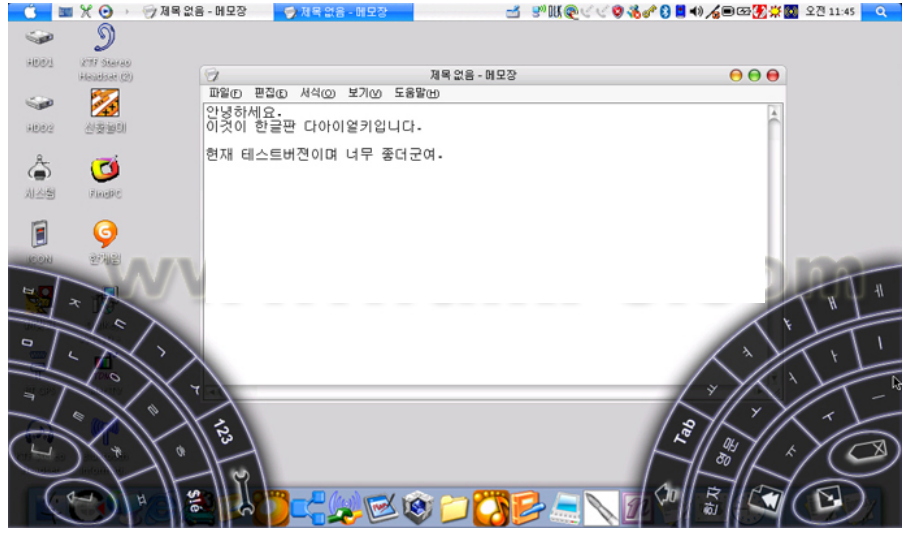


- Two main types (based on the driving electronics)
 - PMOLED (Passive-Matrix OLED)
 - Simpler electronics, no storage capacitor
 - Lower cost
 - Lower lifetime (due to the higher voltage needed)
 - Limited size and resolution
 - Mostly used for simpler displays, e.g. mp3 players, mobile phone sub-displays, etc.
 - AMOLED (Active-Matrix OLED)
 - Contains storage capacitor to maintain the pixel line state
 - No restrictions on size and resolution
 - More costly
 - Used for higher quality screens, such as mobile phones (Blackberry Priv, HTC One A9, Samsung Z3, Samsung Galaxy S10, Microsoft Lumia 950 XL, Apple iPhone X, etc.)

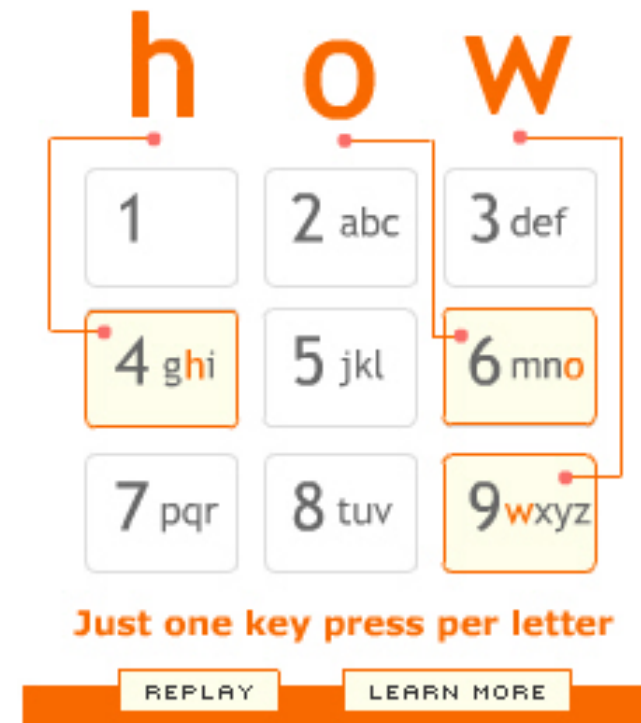
- Introduction
- Categorisation of Mobile Devices
- Components of Mobile Devices
 - Accumulators
 - Processors, Memory, and Storage
 - Display
 - Means for I/O
 - Device Input
 - Personal Area Networks (PAN)

Currently, the following input solutions for mobile devices exist:

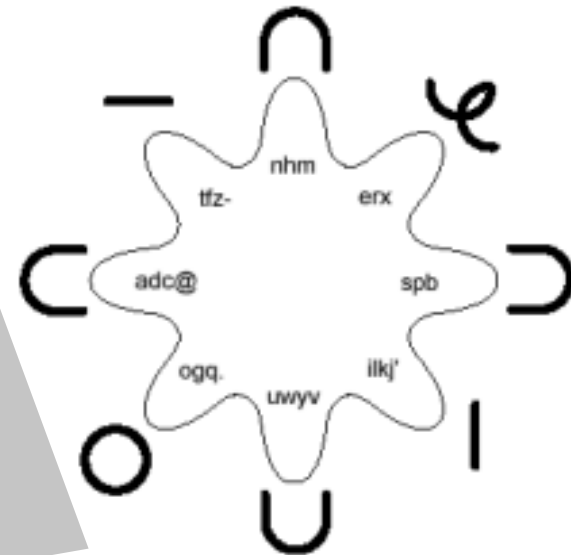
- QWERTY-Keyboard
- Palm-Graffiti
- Tegic T9
- Octave
- SWYPE
- Recognition of handwriting
- Speech recognition

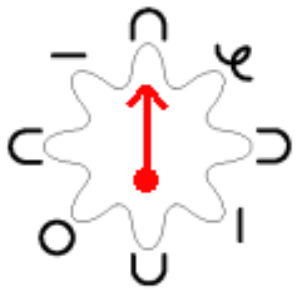


- T9 (*Text on 9 keys*) is a predictive text technology developed by Tegic Communications.
- Widely used by: LG, Samsung, Nokia, Siemens, Sony Ericsson, Sanyo
- Uses a dictionary of words, which is used to look up all the possible words, corresponding to the sequence of keypresses.
- Available in 27 languages

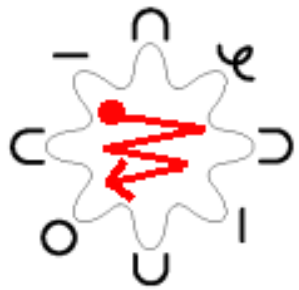


- Characters can be input by either pen or button.

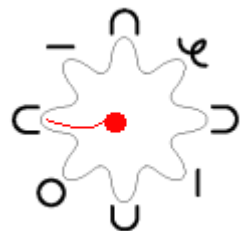




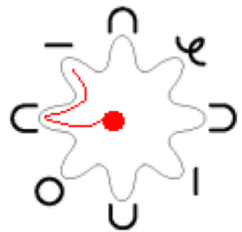
“capital letters”



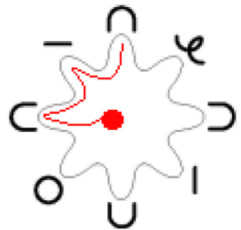
“reset”



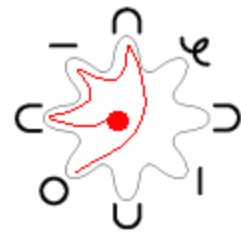
a·



at·



ath·ens



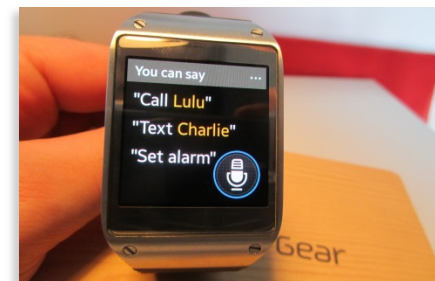
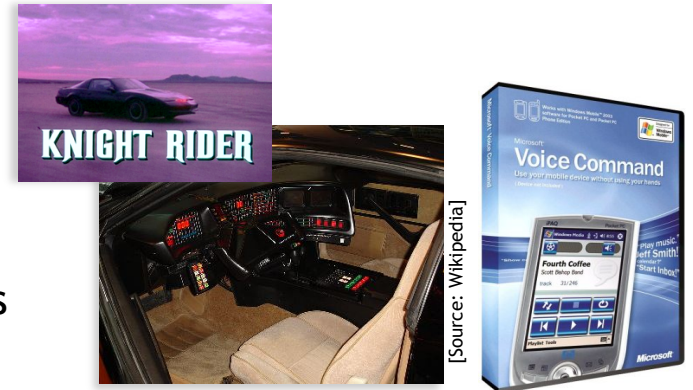
atmo·sphere



[<http://swypeinc.com/product.html>]

- Input by sliding a finger or stylus from letter to letter, lifting only between words
- Word is guessed using error-correcting algorithms and language model
- Developed by Swype Inc.
- First commercially available on Samsung Omnia II (on Windows Mobile 6.5), also available for Android

- Translation of spoken words into text
- Supports various applications, e.g. for
 - initiation of phone calls
 - message composition
 - ...
- Originally performed directly on PDAs/smartphones
- Nowadays usually provided as a cloud service
 - Voice is recorded and compressed
 - Sound file is sent to a server where the actual recognition process is performed
 - Text is sent back to smartphone
- Examples
 - Apple Siri
 - Google Now
 - Samsung S-Voice
 - Amazon Alexa
 - Windows Phone Voice Control
 - Blackberry 10 Voice control
 - ...
- May become important feature for smart watches
- In contrast, term *voice recognition* refers to *identity* of the speaker, not *what* is said.



- Introduction
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- Personal environment, short range
- ***Purpose:*** Connection of devices in short range, for example mobile device and printer.
- Replaces cable-connections:
 - Infrared Data Association (IrDA)
 - Bluetooth
 - Near Field Communication (NFC)

- IrDA: Infrared Data Association (1993):
- Standardized infrared-protocols
- Asynchronous, serial connections up to 115 kbit/s (Serial Infrared) or 4 Mbit/s (Fast Infrared)
- Point-to-Point
- Protocol-family for various purposes



- Exemplary applications:
 - Transmission of mobile business cards
 - Sales data extraction from cigarette vending machines
 - Connection between mobile and laptop
 - Wireless printing
 - Remote control for consumer electronics, e.g. TVs

- Attributes:
 - Wireless
 - Range of up to 10 meters
 - Illumination-angle 15 - 30 degrees
- Disadvantages:
 - **Sounding:** If the infrared-ray misses the target
 - Optical connection required
 - Short interruptions of the optical connection, e.g. between laptop and mobile phone in trains, lead to complete network-interruption.

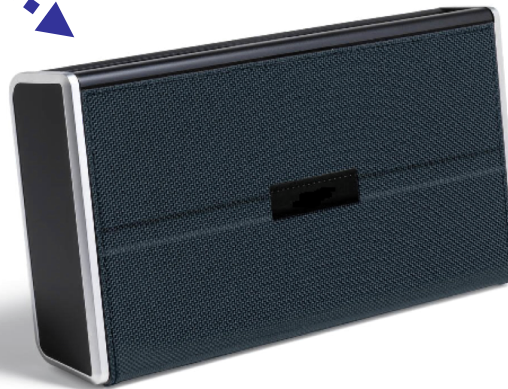
- Frequency range of 2.4 GHz
- Simple and cheap possibility to set up ad-hoc networks of limited range (up to 10 meters)
- No official standard, but de-facto-standard
- Consortium: Ericsson, Intel, IBM, Nokia, Toshiba, etc.
- v5 (2016) improved speed, privacy, and connectivity (support for the Internet of Things)
- Broadly supported by related industries:
 - Computer hardware
 - Software
 - Consumer electronics
 - ...

Personal Area Network (PAN)

Popular Bluetooth Applications

Sound transmission
(to earphones, headphones
or Hi-Fi equipment)

Wireless communications between devices
(Bluetooth-Headset)



- Connection of periphery-devices (headsets, keyboards, mice, etc.)
- Setting up of ad-hoc networks for spontaneous data exchange
- Ad-hoc connection of different networks (e.g. laptop ↔ mobile or phone ↔ GSM ↔ net)
- Applications similar to applications based on infrared technology
- Weaknesses of infrared technology were overcome
 - Increased bandwidth (up to 865.2KBit/s)
 - No optical connection between devices necessary
 - Expanded range (up to 10m)
 - Allows setting up of ad-hoc networks instead of point-to-point connections

Personal Area Network (PAN)

Near Field Communication (NFC)

- Enables radio communication between
 - two NFC compatible devices (two active devices),
 - An (active) NFC device and an (unpowered, passive) tag
- NFC based on existing radio-frequency identification (RFID) standards
- Range: 10 cm or less
- Transfer rates between 106 kbit/s and 424 kbit/s
- Three major modes of NFC
 - Reader/Writer Mode
 - Card Emulation Mode (referred to as "Digital Wallet")
 - Peer-to-Peer Mode



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