VI. Mobile Devices Hardware: Displays

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1. Production technologies

LCD (Liquid Crystal Display)

- An LCD, or liquid crystal display, is a type of screen that uses the properties of liquid crystals to change their optical properties when subjected to voltage.
- LCD screens can be produced in much larger sizes than CRT screens, are more energy-efficient, and because they do not use phosphors, they do not experience the discoloration of part of the screen that we know from old TVs.

1. Production technologies

LCD (Liquid Crystal Display)

- Because they consume relatively little power, LCD screens can safely be supported by devices that use a battery. That's why they're the most popular choice for screen technology on smartphones and tablets.
- There are many different types of LCD panels, and each of them has a specific principle of operation. The most popular and commonly used types are three: TN, IPS and VA.

1. Production technologies

TFT-LCD (Thin Movie Transistor - Liquid Crystal Display)

- In these displays, each pixel is connected to a silicon transistor that adjusts the brightness and color of the pixel.
- The use of transistors for each pixel is called "active matrix TFT". TN (Twisted Nematic) effect displays a black-and-white image, and color images are formed from three-pixel groups using red, blue, and green filters.
- The displayed picture is illuminated by a light placed behind the liquid crystal panel.

1. Production technologies

TN (Twisted Nematic) TFT

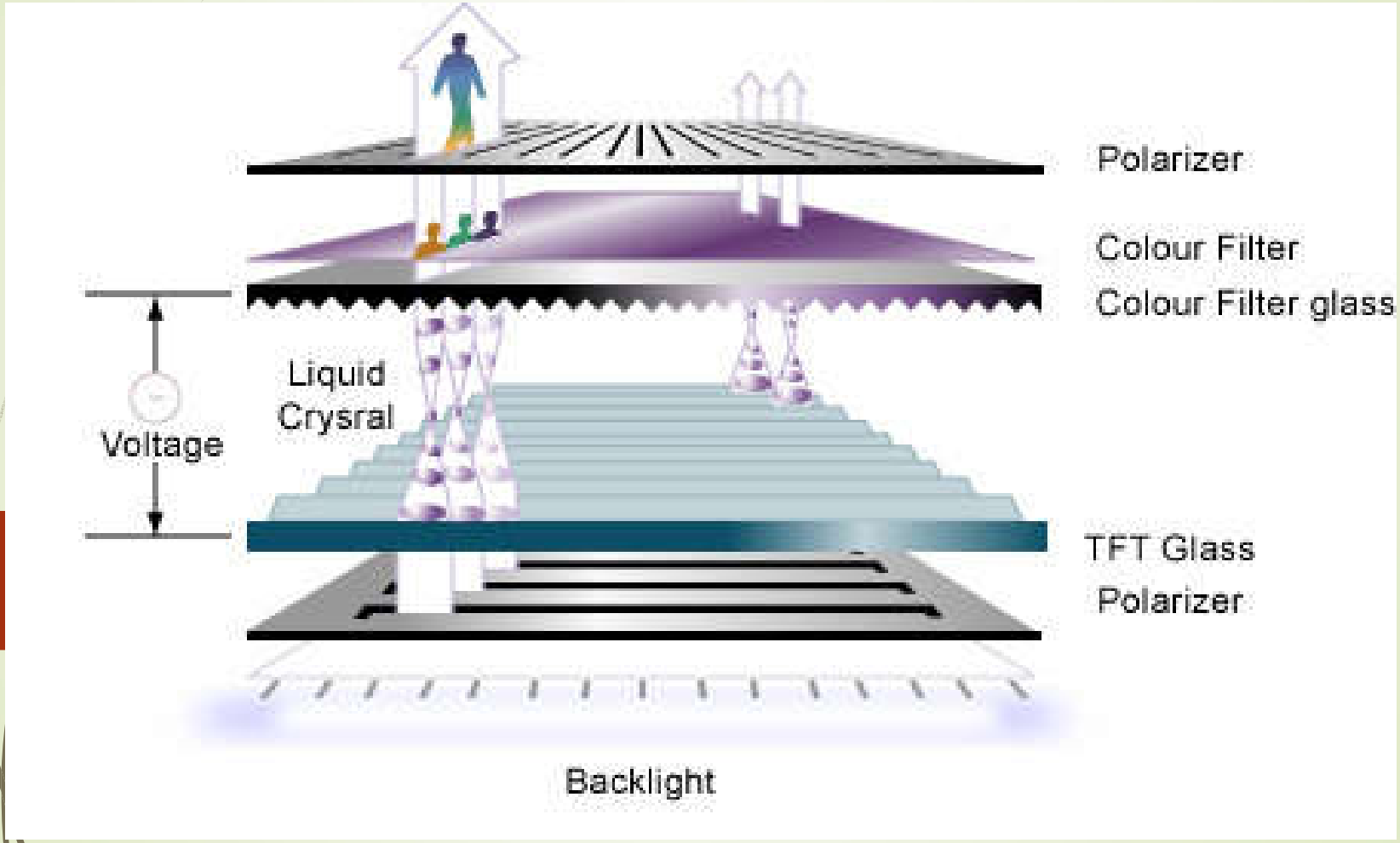
- Twisted Nematic is a term used by smartphone manufacturers instead of TFT LCD.
- TN panels are the cheapest to manufacture and therefore the most popular.
- also quite fast, with a response time of just two milliseconds – making them the fastest type of LCD display, albeit slower than OLED panels.
- Thanks to this feature, they are particularly good at rendering fast-moving objects and are often used in the creation of 3D displays.

1. Production technologies

TN (Twisted Nematic) TFT

- Their disadvantage is that they do not support as many colors as other types of panels, which also affects the final image quality.
- In addition, with TN panels, the viewing angle is very small, that is, if you look from the side, the cvets are changing.

Basic diagram of TFT LCD display



1. Production technologies

TN (Twisted Nematic) TFT

- **Working principle:** light enters through a polarizing filter that aligns the light waves in one direction and then passes through the TN liquid crystal.
- The molecules of this crystal twist the light 90 degrees (hence their name), then this light passes through a color filter that colors it red, green, or blue.
- Finally, the light reaches a second polarization filter positioned perpendicular to the first one.

1. Production technologies

TN (Twisted Nematic) TFT

- When a voltage is applied to the liquid crystal, it changes its twisted shape, changing the orientation of the light. In this way, more of the light is blocked by the second polarizing filter.
- Each pixel in a TN panel contains three rectangular sub-pixels - red, green and blue. By varying the voltage of each of the crystals in these subpixels, the three primary colors are mixed and the remaining secondary colors are created.

1. Production technologies

In-Plane Switching (IPS)

- In 1996, Hitachi introduced IPS technology, which aims to overcome the drawbacks of TN TFT.
- With IPS technology, each of the three subpixels can display 8-bit brightness, which means more realistic color.
- In addition, IPS screens support a wider range of colors, which also explains why they are used in high-tech monitors for working with video, photography or for design.

1. Production technologies

In-Plane Switching (IPS)

- With IPS, the viewing angles are much larger: practically, wherever we look at the screen, the colors will be almost the same.
- This explains why most smartphones and tablets today use IPS screens.
- The disadvantages of IPS screens over TN TFT screens are that they are not as bright and as fast. For this reason, they are not the basis of 3D displays. Another disadvantage is that they are more expensive to manufacture.

1. Production technologies

In-Plane Switching (IPS)

- **Working principle:** the structure of the IPS display is almost the same as that of the TN TFT display. Only the structure of the crystals is different - they are all arranged horizontally.
- In TN TFT, moreover, the crystal is located between two electrodes, while in IPS, the crystal is above the two electrodes.
- This structure takes up more space and explains why IPS screens are not as bright - this arrangement simply lets in less light.

1. Production technologies

In-Plane Switching (IPS)

- When the crystal is stressed, the structure rotates 90 degrees parallel to the flat panel of the display.
- The more tension is applied, the more the structure will rotate and the more light will pass through.

1. Production technologies

In-Plane Switching (IPS)

- Sometimes smartphone manufacturers refer to their displays as "IPS LCD" or "TFT IPS LCD", but in some cases they use their own trade names:
  - **Retina** – this name is used by Apple for high-resolution IPS LCD displays manufactured by the company LG. Used in devices after iPhone 4 and iPad 3.
  - **NOVA** – this is LG's trade name for their extremely bright and energy-efficient IPS LCDs.
  - **Super LCD 2** – this is the second generation of S-LCD produced by Sony, which switches from TN to IPS technology. They show very good colors, very high contrast and viewing angles.

1. Production technologies

VA (Vertically aligned)

- VA displays can conditionally be positioned between IPS and TN TFT displays.
- In general, they transmit color more realistically than TN and, like IPS, support 8-bit brightness, but do not provide as wide a range of colors as IPS panels.
- Angles are also larger than those provided by TN, but smaller than those provided by IPS.
- The same thing applies to response time: VA displays are slightly faster than IPS screens, but slower than TN TFT displays.

1. Production technologies

VA (Vertically aligned)

VA panels are divided into two types: MVA and PVA.

- **MVA (Multi-domain vertical alignmen)** transmit the black color much better and usually maintain quite good contrast.
- **PVA (Patterned vertical alignment)** panels are a bit cheaper and not quite as good, although the updated technology – S-PVA - tackles the biggest color rendition issues.

1. Production technologies

VA (Vertically aligned)

- **Working principle:** the structure of VA panel is similar to that of TN TFT panel. Again, the difference is in the structure of the crystals themselves.
- When there is no voltage, the crystals are arranged perpendicular to the display, blocking all the backlight.
- When stressed, the crystals line up horizontally and allow light to pass through.
- Both MVA and PVA, the crystals are oriented at different angles so that the same thing is seen no matter what position the screen is viewed from.

1. Production technologies

Types of backlighting on LCD displays

- One of the most important features of LCD displays is the backlight. The backlight is the lighting that makes liquid crystal displays work.
- Unlike CRT displays, LCD displays do not create this lighting themselves, but need a special lighting fixture. This lighting is called "backlight" because it illuminates the display from below, although it can also do so from the sides.
- The two main types of backlight used are CCFL and LED. Today, all devices use LED technology.

1. Production technologies

CCFL backlight

- The abbreviation comes from "cold cathode fluorescent lamp".
- Before 2010, this was the most popular type of backlight in TVs and monitors. Large displays typically used either two lamps located at opposite corners of the LCD panel, or a row of lamps behind the panel.
- In recent years, CCFL backlighting has lost its lead to LED due to several disadvantages: too much power consumption and too high voltage need, forcing a thicker panel design and faster aging.

1. Production technologies

LEDs backlight

- LED backlight is divided into two types: white LED backlight and RGB LED backlight.
- Almost all tablet or smartphone screens use a white LED backlight.
- Usually a blue LED with an additional broad-spectrum yellow phosphor, and the result of this combination is white light.
- Since the curvature of the spectrum, however, is yellow at its peak, the red and green colors also "yellow", which narrows the range of colors that this type of display supports.

1. Production technologies

LEDs backlight

- RGB backlighting, on the other hand, contains red, blue, and green LEDs and can be controlled to create white with different color temperatures.
- This type of backlight is, of course, more expensive and is found in high-end laptops or monitors.

1. Production technologies

LEDs backlight

- Although better than CCFL, LED technology also has its drawbacks.
- of all, it is difficult to achieve uniformity in lighting, especially in the aging process of the LEDs.
- The unevenness is caused by the fact that each diode ages at a different rate.
- The aging of the diodes also changes the white color - something that is noticeable in both types of LED backlight.

1. Production technologies

LEDs backlight

- And yet, LED technology has two undeniable advantages.
- First of all, since 2010, their energy consumption has been greatly reduced - a key factor that greatly affects the battery performance of tablets and smartphones.
- Most LED backlights offer "corner lighting", that is, several diodes are located at the corners and illuminate the LCD panel from below.
- The advantage of this design is that it allows the panels to be both thinner and cheaper to manufacture.

1. Production technologies

LEDs backlight

- There is also a more expensive version of the LED backlight, where the panel is illuminated not only on the corners, but on the entire surface behind the panel.
- This design uses a technology called "local dimming". This intelligent technology enables the achievement of darker black pixels depending on the display image.

1. Production technologies

Advantages of LCD:

- cheap to manufacture;
- IPS displays display colors accurately;
- Slight possibility of color change;
- bright and can be read in outdoor environments.

Disadvantages of LCD:

- due to the need for backlighting, high contrast and completely black color cannot be obtained;
- TN displays have a small viewing angle;
- in most cases, they are energy intensive and physically thick.

1. Production technologies

OLED (Organic Light-Emitting Diode)

- OLED displays are a relatively new technology.
- They contain an organic substance that emits light.
- That's why OLED displays don't need backlighting (which LCDs do).
- This means they are easier to make, cheaper and more energy efficient than LCDs, and can even be transparent and flexible.

1. Production technologies

OLED (Organic Light-Emitting Diode)

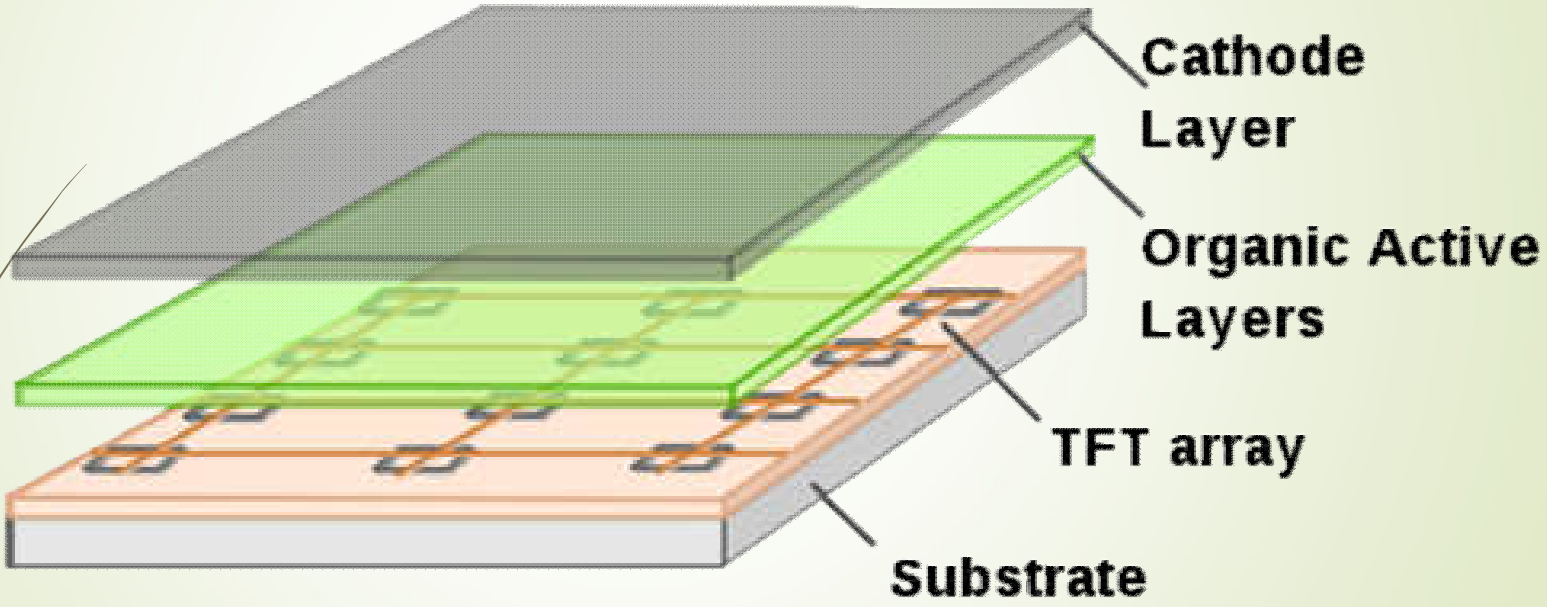
- **AMOLED**. While LCD displays consist of a set of different layers that work in concert to reproduce an image, AMOLED displays are simpler in construction.
- AMOLED stands for Active-Matrix Organic Light-Emitting Diode, which means that the display emits colors directly from organic diodes and does not need polarization filters, crystals and backlighting.

1. Production technologies

OLED - AMOLED

- The way the AMOLED display works is very simple. At the bottom is a transistor layer that controls the voltage to the upper organic layer.
- When a voltage is applied to organic diodes they emit light, like hers color depends on the molecular structure of the diode.
- The intensity of the light can be changed depending on the voltage supplied by the transistors, which allows the production of millions of colors, similar to the rotation of liquid crystals in LCD displays.

Diagram of an AMOLED display



1. Production technologies

OLED - AMOLED

- Because LEDs emit light, they do not need any backlighting.
- This helps not only to reduce consumption, but also to significantly reduce the thickness of the display, which is an advantage for phones that need to be as thin as possible.
- The absence of constant backlighting ensures high contrast, since to obtain a black color the organic diodes only need to be turned off (no voltage should be applied to them).

1. Production technologies

OLED - AMOLED

- There are also some downsides to AMOLED displays.
- Since red, green, and blue subpixels are used to produce the full range of colors, different organic compounds must be used to provide each of the three colors.
- The properties of each mixture vary greatly and it is very difficult for each diode to emit light of the same intensity at full power. This leads to a number of problems. If a color is too intense it can add a slight tint to the display.

1. Production technologies

OLED - AMOLED

- Blue LEDs are usually the cause of white web pages looking bluish.
- Because AMOLED displays are very sensitive to diode intensity, color reproduction is not as accurate as IPS LCD.

1. Production technologies

OLED - AMOLED

- The last problem is the life of the different types of diodes.
- Because each color is produced by a different organic chemical compound, the diodes can "live" (or emit light) for different times, depending on the color.
- In early versions of AMOLED displays, blue diodes were found to "die" twice as fast as green ones.
- In recent versions, the technology has been significantly improved and this is not observed.

1. Production technologies

OLED - AMOLED

- As with LCD displays, there are trade names indicating a particular company's use of the technology:
  - **Super AMOLED**. This is the first generation of the display developed by Samsung. In this display, the touchscreen technology is included in the manufacturing process, which saves overlaying it at a later stage and ensures better reading in outdoor conditions.
  - **Super AMOLED Plus**. This is the new generation of Samsung AMOLED, which instead of the old PenTile matrix uses a new RGB matrix for better color reproduction. It was first used on the Samsung Galaxy S2.

1. Production technologies

OLED - AMOLED

- **HD Super AMOLED**. "Super" means that the Samsung display has integrated touchscreen technology, and the lack of "Plus" means that a PenTile matrix is used. HD means that the display supports HD resolution.
- **ClearBlack AMOLED**. Used by Nokia. This AMOLED display has a "ClearBlack" coating with anti-reflective polarization that improves reading in outdoor conditions.

1. Production technologies

OLED - AMOLED

Advantages of AMOLED:

- very thin and sometimes flexible;
- bright colors and high contrast thanks to organic diodes;
- excellent viewing angles;
- low energy consumption.

Disadvantages of AMOLED:

- sometimes there is inaccurate representation of colors;
- shorter life compared to LCD displays.

2. Sensor technologies

- In 2012, at least 18 different touch technologies existed. Today there are probably even more. Some of them rely on visible or infrared light, others use sound waves, and still others use force sensors.
- Two proved to be the most popular among these technologies: resistive and capacitive.
- These technologies are very different: one detects touch by relying on the electrical resistance created, the other by capacitance.
- Multitouch. This is the name of the technology allowing to recognize simultaneous touches in several points on the touch screen.

2. Sensor technologies

Resistive touch displays

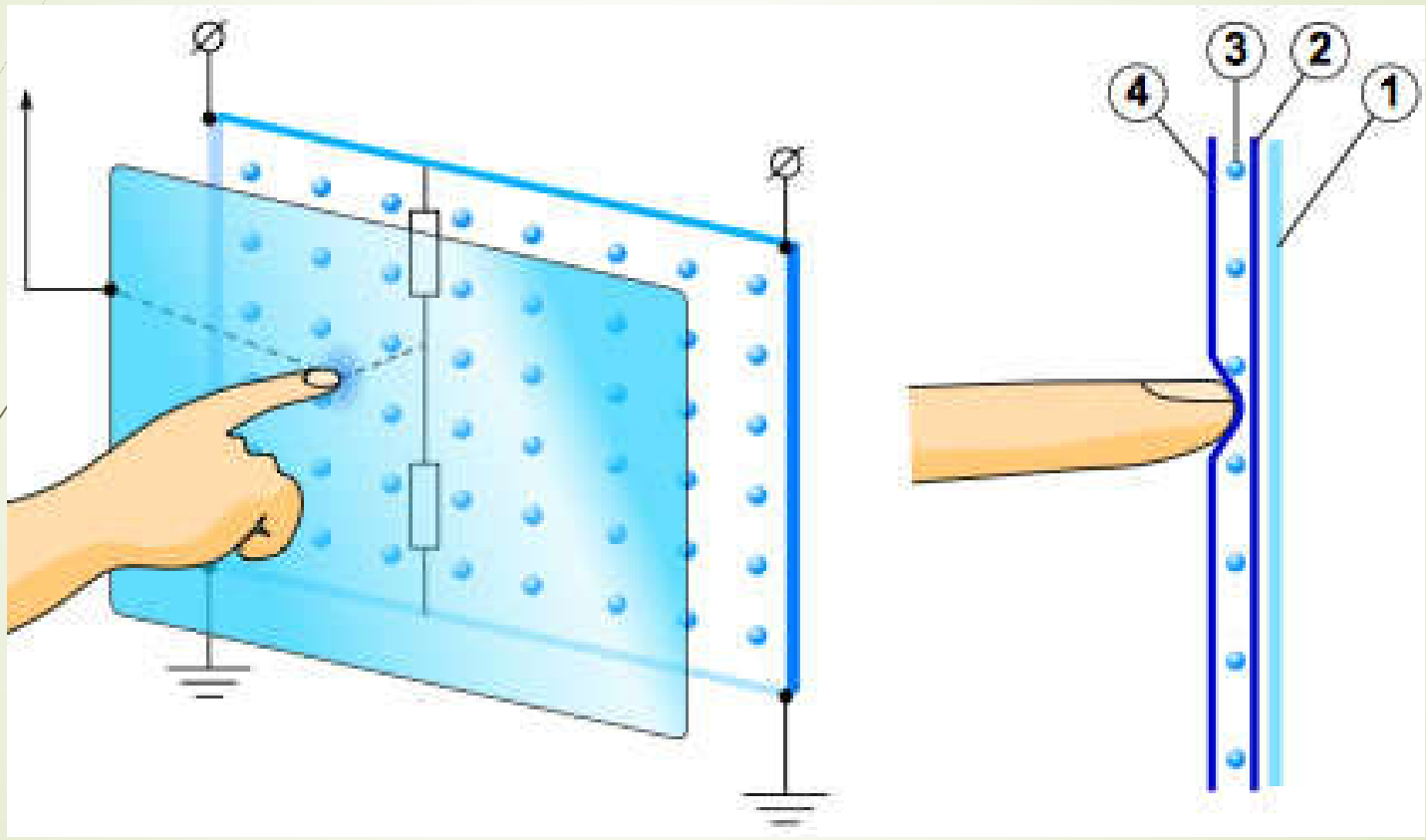
- This type of panel measures what change in resistance occurs when a point on the screen is pressed.
- The panels are composed of two layers: usually the lower layer is made of glass, and the upper one is a plastic film.
- When we touch this film, it, in turn, makes contact with the glass and creates an electrical circuit.

2. Sensor technologies

Resistive touch displays

- Both layers are usually covered with a transparent material with conductive properties, and the electrodes on one layer are located at the same angle to the electrodes on the other.
- When we touch the touch screen, contact is made between the grid of the glass and the grid of the film; the circuit voltage is measured and the X and Y coordinates of the touch position are calculated based on the resistance level.
- The created voltage is then converted into a digital signal thanks to analog-to-digital conversion.

Principle of operation of a resistive display



2. Sensor technologies

Resistive touch displays

- An advantage of resistive touch screens is that they are relatively cheap to manufacture and can be operated with almost anything that has a pointed tip (stylus, pencil or finger).
- However, their disadvantages are many. They often need to be recalibrated.
- The material from which the transparent is made can crack after prolonged use, creating a "dead zone" on the screen.

2. Sensor technologies

Resistive touch displays

- In addition, there must be some space between the two mentioned layers, which is usually filled with air. This makes these panels both thicker and better quality, as the air has a different index of light reflection than the two layers it is between. Resistive screens are therefore not suitable for use in direct sunlight.
- The biggest disadvantage of resistive screens, which eventually made capacitive more popular is the lack of support for multitouch - touching with several fingers at the same time.

2. Sensor technologies

Capacitive touch displays

- This type of display is created using a technology known as "projected capacitive resistance" (pro-cap or p-cap).
- Capacitive screens use technology that determines the change in charge.
- The older generation of capacitive screens are coated directly with a conductive layer. This method, however, has proven ineffective because the sensitive layer is damaged too quickly.
- Modern capacitive screens feature a second conductive coating layer.

2. Sensor technologies

Capacitive touch displays

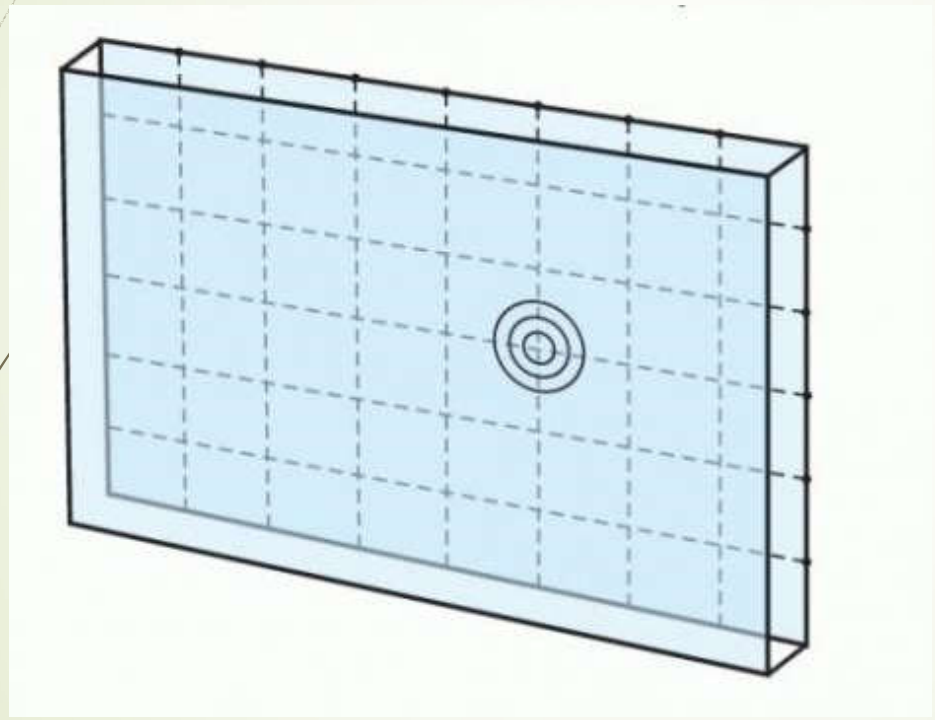
- The capacitive ones displays are composed of two conductive layers, between which there is an insulating material, usually a thin layer of glass.
- Unlike resistive displays, the layers here do not bend and there is no air between them, therefore their life is longer.
- On the reverse side of the screen, a network of wires (or rows of electrodes) is applied to which a weak current is applied.
- The conductors in each layer are separate so that their capacitive resistance can also be measured separately.

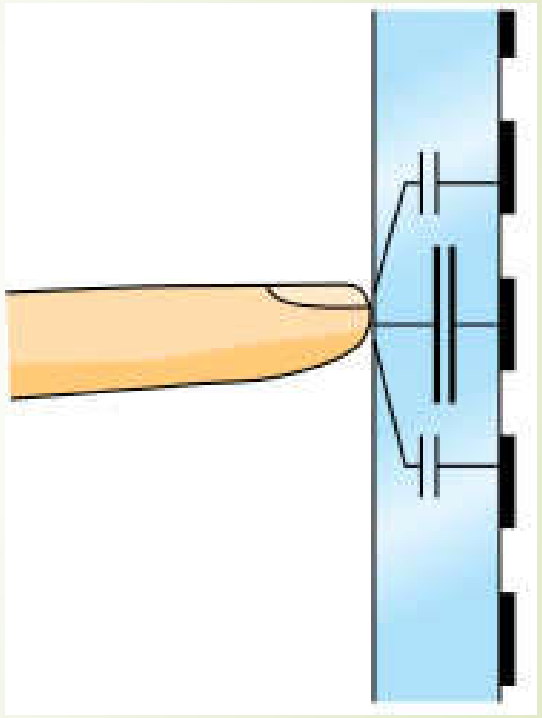
2. Sensor technologies

Capacitive touch displays

- At the point of contact, the electrical capacity changes, and the controller determines at which point of intersection of the electrodes this happened and determines the coordinates.
- Since each wire is measured separately, the panel can identify many simultaneous touches in different places – it can support multi-touch.

Principle of operation of a capacitive display





2. Sensor technologies

Capacitive touch displays

- The multitouch in question varies, with phones usually supporting five fingers and tablets supporting ten fingers multitouch.
- Multi-touch support requires significant computing performance, making the touchscreen controller expensive.
- Also, the capacitive screen can only be operated with conductive material (e.g. fingers), but not with most styluses.

2. Sensor technologies

Other types of sensor technology

- There are also other sensor technologies - for example, using a network of infrared rays or generating ultrasonic waves.
- There are also systems using cameras tracking the movement (multitouch is also used here), as well as technologies using tenso coating, the deformation of which changes the electrical resistance.

3. Basic characteristics of displays

- There are several technical features of displays that affect the overall quality of the content we handle:
- Resolution;
- Brightness;
- Aspect ratio;
- Range of colors;
- 18-bit/24-bit color;
- Visual angles;
- Reaction time;
- Protective glass.

3. Basic characteristics of displays

Resolution

- The most popular types of resolution used by modern smartphones and tablets are:
  - HVGA: 480X320
  - VGA: 640X480
  - WVGA: 800X480
  - FWVGA: 854X480
  - WXGA/HD: 1280X720
  - HD+: 1600X900
  - FHD: 1920X1080

3. Basic characteristics of displays

Brightness

- The brightness of a display is measured in Cd/m^2 - candela per square meter.
- What you should pay special attention to is the directly proportional relationship between the brightness level and battery life. The brighter the screen, the faster the battery will drain.
- must also take into account the fact that a screen set with too high or too low brightness causes eye fatigue after prolonged use.

3. Basic characteristics of displays

Aspect ratio

- A device's aspect ratio can be calculated by dividing the vertical by the horizontal resolution of its screen.
- ratio of 16:9 is also called " wide angle " and is suitable for watching movies and videos. It is common among smartphones and tablets.
- But there are also those that use 4:3 ratios, which are closer to the book format we're used.

3. Basic characteristics of displays

Color range

- This is the range of colors that a display reproduces. It is mistakenly believed that the more saturated it is, the better.
- In order to see colors realistically in photos and videos, the display should support the standard color gamut that is used in content creation and is called sRGB.
- That is, a display that supports a more saturated gamut will not be able to reproduce more colors in a photo than are recorded in it. Consumer-grade LCD screens often support a smaller gamut than sRGB.

3. Basic characteristics of displays

18-bit and 24-bit color

- Most displays support so-called 24-bit color. Each of the three primary colors needs 256 intensity levels, which equates to 8 bits. Since there are three, the primary colors create a total of 24 bits.
- some devices use lower-quality displays where primary colors only have 64 shades or 6 bits, which when multiplied by three becomes 18 bits. These displays sometimes produce sharp edges when reproducing high-contrast objects.

3. Basic characteristics of displays

Viewing angles

- This term refers to the full angle (compared to 180 degrees) at which we can view the screen without a noticeable change in colors.
- In practice, this means that with a viewing angle of 170 degrees mentioned in the product description, the image is perfectly visible at an angle of up to 85 out of a total of 90 degrees.
- Often, however, these angles are illusory, since in their range, colors are preserved, but the level of contrast is visibly reduced. With the budget screens, at a viewing angle of 15 degrees, the changes in colors are already clearly visible.

3. Basic characteristics of displays

Reaction time

- Response time measures in milliseconds how quickly the display reacts when playing different types of content. This is actually the time it takes to change a pixel from one color to another.
- Standard video content, for example, refreshes at a rate of 25-60 frames per second, meaning that frames rotate at a maximum of 17 milliseconds.

3. Basic characteristics of displays

Protective glass

- There are currently four main technologies used to protect displays :
  - Gorilla Glass
  - Dragontrail
  - Tempered glass
  - Sapphire glass
- Huawei company is starting to use its own developed glass - Kunlun Glass - in its smartphones. Conducted experiments show that the Huawei Mate50 Pro smartphone using Kunlun Glass can be dropped from 4.2 m without damage because it contains 10,000 trillion nanocrystals to prevent cracks.

3. Basic characteristics of displays

Corning Gorilla Glass

- They are used in 4.5 billion mobile devices, which is 73% of all devices.
- Gorilla Glass has gone through five stages of development, and they are as follows :
  - 2005 - 2012 First series used in iPhone;
  - 2012 - 2013 Second generation, which is 20% thinner than the first and used in over 1 billion devices;
  - 2013 - 2015 Third generation, which is 40% more scratch resistant than the previous one and 3 times stronger;

3. Basic characteristics of displays

Corning Gorilla Glass

- 2015 Fourth generation characterized by the content of silver ions, which kill up to 90% of bacteria. They are twice as strong as the third generation and after tests provide 80% more protection. The thickness is only 0.4 mm.
- 2016 Fifth generation. It is stronger and drop resistance is increased by 60%. Gorilla Glass 5 remains strong in 80% of cases of drops from a height of 1.60 meters, i.e. from the shoulder level of an adult.
- 2016 Gorilla Glass SR+ provides scratch resistance comparable to alternative expensive protective materials. 70 % better than alternatives in terms of impact damage and 25% better in terms of reflectivity.

3. Basic characteristics of displays

Corning Gorilla Glass

- 2018 Sixth generation. Gorilla Glass 6 withstands up to 15 drops from a height of one meter and is up to twice as good as Gorilla Glass 5.
- 2020 Seventh Generation. Gorlla Glass Victus - durability at multifaceted falling from a height of up to 2 meters onto hard and rough surfaces. Twice the scratch resistance of Gorilla Glass 6.

- Despite its strength, the main disadvantage of Gorilla Glass is the possibility of micro-scratches, most often caused by sand.

3. Basic characteristics of displays

Dragontrail Glass

- Dragontrail Glass is manufactured by the Japanese giant Asahi Glass and is the second most popular brand among mobile device manufacturers.
- Dragontrail Glass is available in several variants - Dragontrail, Dragontrail X and Dragontrail Pro.
- Dragontrail The 2016 Pro is the company's latest product, offering 30% better drop resistance and greater flex resistance than the standard Dragontrail.
- Google Pixel 3a and Pixel 3a XL smartphones use Dragontrail glass instead of Corning Gorilla Glass. This glass is also used in newer devices such as the Realme X7 Max.

3. Basic characteristics of displays

Tempered glass

- It's the cheapest solution and is the preferred material for many smaller manufacturers' screen protectors.
- Tempered glass is first cut to size and then heated in a furnace to just over 600 degrees. It is then rapidly cooled with cold air for a few seconds.
- This process makes the outer surface of the glass cooler than the inner, creating compression on the outside and tension on the inside. In this way, a stronger glass is obtained.

3. Basic characteristics of displays

Tempered glass

- Tempered glass usually has a strength that is six times that of ordinary glass.
- Tempered glass also has disadvantages:
  - Due to internal stresses, any damage to the edges of the glass causes it to break into small pieces. This is the reason why it is cut before quenching and cannot be machined afterwards.
  - The surface of tempered glass is softer than that of ordinary glass and is more prone to scratches.

3. Basic characteristics of displays

Sapphire glasses

- The alternative to Gorilla Glass is sapphire glass.
- Sapphire as a material has different varieties, but the one used in mobile devices is white sapphire.
- The material is second in strength (after diamond).

3. Basic characteristics of displays

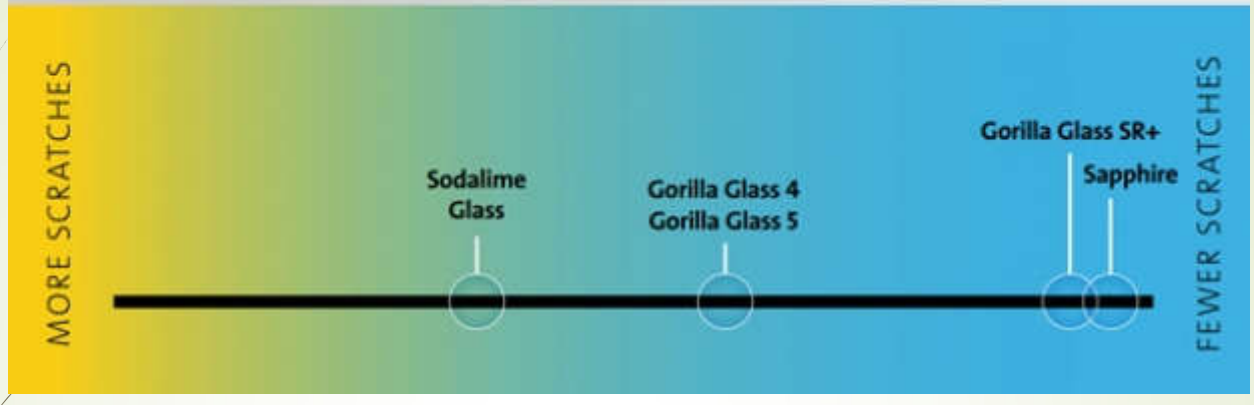
Sapphire glasses

- The sapphire coating has several main disadvantages:
  - The production cost per inch is a few dollars, while that of Gorilla Glass is over 10 times lower.
  - A much higher level of reflection, which after the appearance of Gorilla Glass 4 becomes a major weakness.
  - The average life of smartphones is 18 - 24 months, which makes it pointless to use such an expensive material.
- The technology is mainly used in watches and in a few smartphone models.

TESTS THAT REPLICATE REAL WORLD USE

The Tumble Test replicates scratch and impact damage from exposure to common contents of a purse.

SCRATCH FREQUENCY SCALE



THINNESS

Materials with a high retained strength best enable thinner and lighter weight device designs. The graph below shows the relative thickness required of different cover materials to achieve similar retained strength.