# Digital Displays Explained

**AMOLED, IPS, PenTile, TFT…is the alphabet soup of display technologies giving you a headache? Our guide tells you what it all means.**

By Jason Cross, PCWorld Mar 18, 2012 8:00 pm

Manufacturers--whether they make phones, tablets, TVs, or computer monitors--are always trying to convince you that their gadget has a better display than all the other gadgets. In doing so, they throw a bunch of fancy-sounding acronyms and technology terms at you:*Super AMOLED. PenTile. LED. IPS. Super-IPS.* Some of the hyped items are legitimate descriptions of new technologies, and some of them are just marketing buzzwords for minor tweaks. This guide will help you better understand how digital display technologies work, and what some of the major terms mean.

At its base, the situation is actually simpler than you might think. You're likely to encounter only three major types of digital displays: LCD, OLED, and plasma. We'll tackle them from least common to most common.

Bear in mind that this article is a simple primer. As complicated as this stuff may seem, this discussion only scratches the surface. You'll learn enough to make informed decisions about the products you buy, but digital displays involve a whole lot more than just the basics covered here.

## Plasma

These days you find plasma displays only on very large HDTVs and digital signs, and LCD is starting to replace plasma even in those situations. Plasma displays have great contrast, with bright whites and dark blacks. Color reproduction is very good, and viewing angles are fantastic--plasma displays don't shift color or brightness very much when you view them from the side--so they're ideal for public places such as sports bars. They're also relatively inexpensive to make in very large sizes. The market used to see a huge price difference between a 50-inch plasma HDTV and an LCD of the same size, though that price gap has largely disappeared today. In addition, plasma displays have a fast response time (that is, they can change the color of a pixel quickly), which means less motion blur.

Unfortunately, plasma has some disadvantages that keep it out of smaller devices. Plasma screens are too thick, heavy, and power-hungry to work well in smartphones or tablets. It's also difficult to pack a lot of pixels into a small plasma screen, so small devices would suffer from low resolutions. On top of that, the technology produces a noticeable gap between pixels that can lead to the dreaded "screen door effect." You can't see it sitting 10 feet away from a big TV, but it would stand out on a laptop or PC monitor.

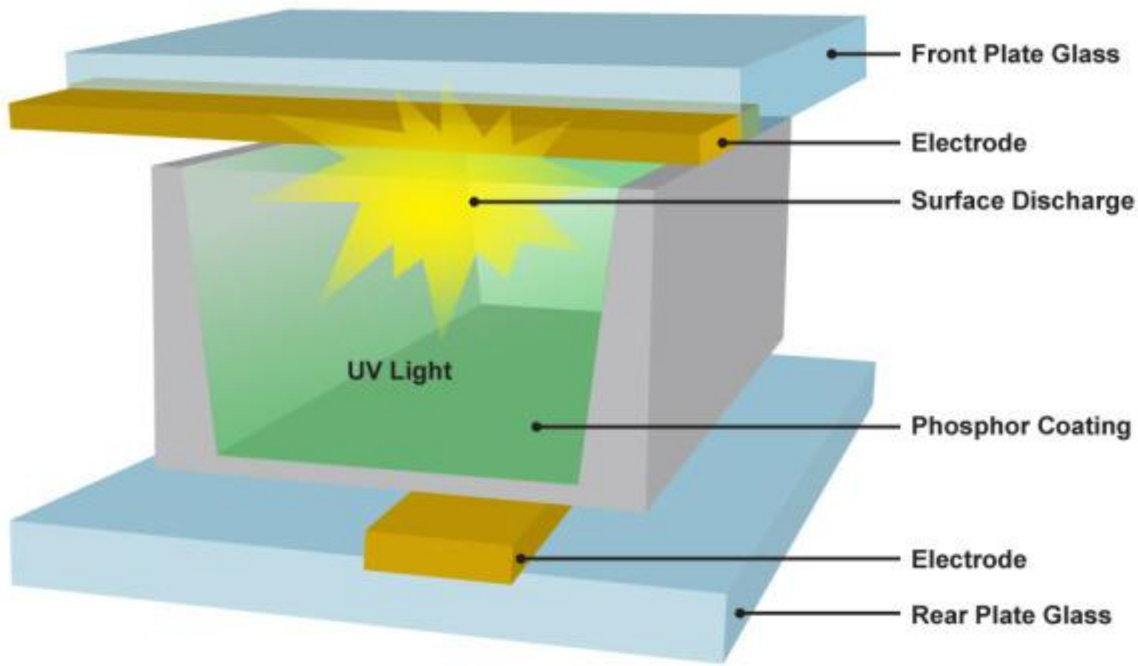



Diagram of a single cell in a plasma display.

**How it works:** A plasma display consists of millions of tiny cells filled with xenon and neon gas, held between two plates of glass. Lines of electrodes run beneath all the cells, and perpendicular lines of electrodes run above them, forming a basic grid. The plasma display controller charges the electrodes beneath and above the cell it needs to light up, and the current passing through the gas in the cell makes it glow. In many ways, it works just like a tiny fluorescent light. The controller lights up the cells each in turn, in a fraction of a second, too fast for the eye to see.
The light that the gas emits is actually in the ultraviolet spectrum and can't be seen by the human eye, but each cell is coated with a colored phosphor--either red, green, or blue. Excited by the ultraviolet light, the phosphors emit visible light.

In short, a plasma display has pixels made up of smaller red, green, and blue subpixels that work like little fluorescent lights, with an electric charge exciting a gas and causing a phosphor to glow. And it all happens millions of times a second.

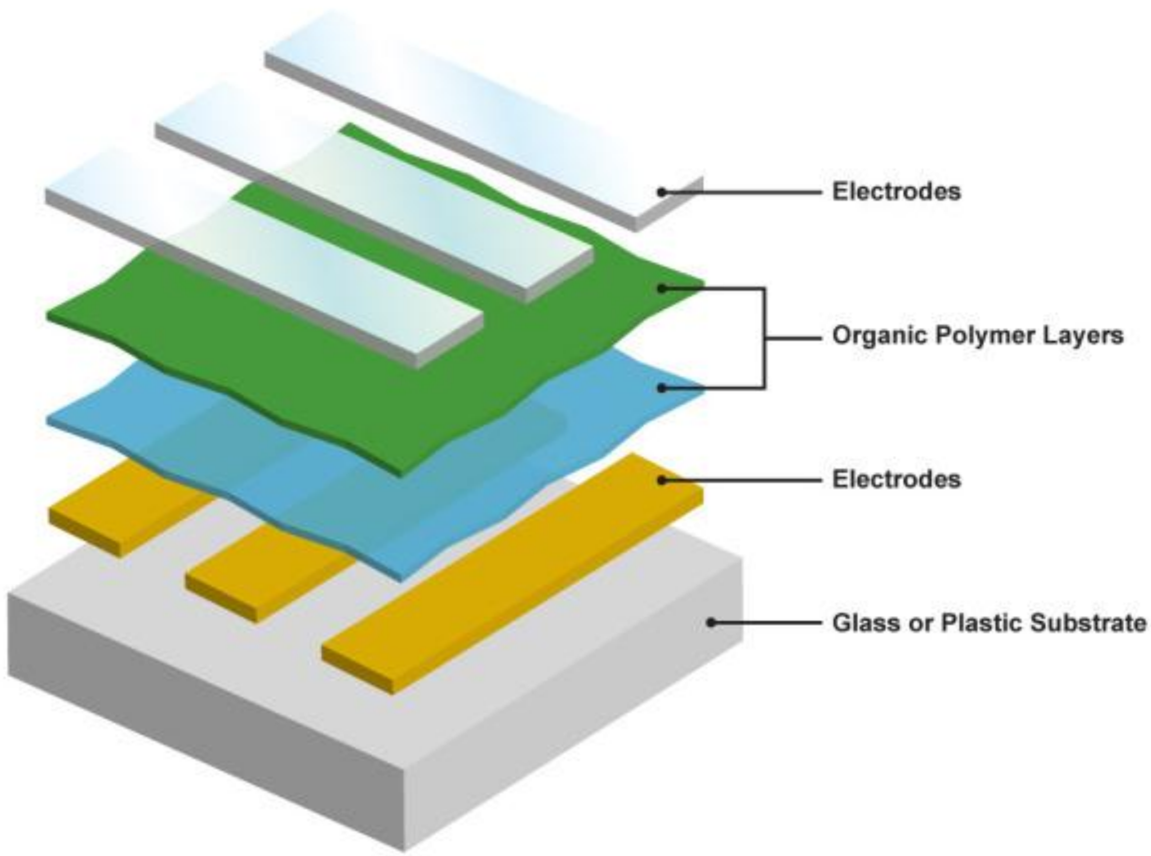
## OLED

Organic light-emitting diode products are the newest digital display technology (at least, in consumer devices). You'll often see [OLED displays]() marketed as AMOLED; the "AM" stands for "active matrix." That term describes how the pixels are addressed: how the display controller directs each subpixel to turn on or off, or to brighten or dim. The label is fairly pointless because virtually all OLED and LCD screens on consumer devices these days use active-matrix addressing--there's nothing special about it. An OLED display works sort of the way a plasma display does, except instead of exciting a gas to create light, the

electrodes excite an organic polymer that emits light. (A polymer is like a big supermolecule made up of linked smaller molecules that repeat over and over.)
OLED technology offers a lot of benefits. It’s quite energy efficient, using as little electricity as the most efficient LCDs do. Because OLEDs directly emit light and don’t rely on a backlight, the displays can be incredibly thin, making them suitable for tablets and smartphones, where every millimeter counts. They also have an incredibly fast response time--with each pixel changing color many times faster than the fastest LCD--so they produce less smearing or motion blur when objects on the screen move quickly. Viewing angles are terrific, with little to no shift in color or brightness at any almost any angle. Contrast is as good as it gets too, because just as in plasma, the cells that are supposed to be black simply never light up at all. Essentially, OLED offers all the major benefits of plasma in a thinner display that can be much smaller and higher-resolution, and is far more energy efficient.

The chief drawback of OLED displays is the cost. They’re considerably more expensive to manufacture than LCDs or plasmas, especially at very large sizes. Some promising advances in OLED manufacturing may make them the cheapest display technology of all, but that day hasn’t come yet. OLED displays also have trouble with blue--the red and green diodes hold up well and are pretty efficient at turning electricity into light, but the blue diodes are less efficient and degrade faster over time. The latest generation of OLED displays has improved the situation greatly, but long-term color balance is still a challenge. Oh, and the amazing energy efficiency of OLEDs has one little gotcha: Although OLEDs are extremely efficient when the pixels are black or dark shades, they can use considerably more energy than LCDs when displaying full white (and the typical Web page or office application has a lot of white pixels).

Super AMOLED and Super AMOLED Plus are marketing terms for variants of standard OLED technology. These displays may have small variations such as a different pattern of red, green, and blue subpixels, or an integrated touch-sensitive layer, but fundamentally they work the same as other AMOLED displays do.




OLED displays use glowing organic polymers to produce colored light.

**How it works:** OLEDs create light via electroluminescence, utilizing a material that emits light when stimulated with electricity. The structure of an OLED display is very much like that of a plasma, only with thin layers of organic polymers instead of cells filled with gas. When current passes through the polymers, electrons give up energy as photons (light). Different polymers are used for red, green, and blue subpixels. As more voltage is applied to each subpixel, it becomes brighter; so by varying the amount of voltage to the red, green, and blue subpixels, you can make a pixel display nearly any color.

## LCD

This is the big one. Liquid crystal displays make up the vast majority of HDTVs, desktop and laptop monitors, and tablet or cell phone displays. This basic technology has been around for a long time, and has greatly improved over the years. Many different types of LCDs are in use today, but only three major classes of LCD--twisted nematic, In-Plane Switching, and patterned vertical alignment--are worth knowing about.

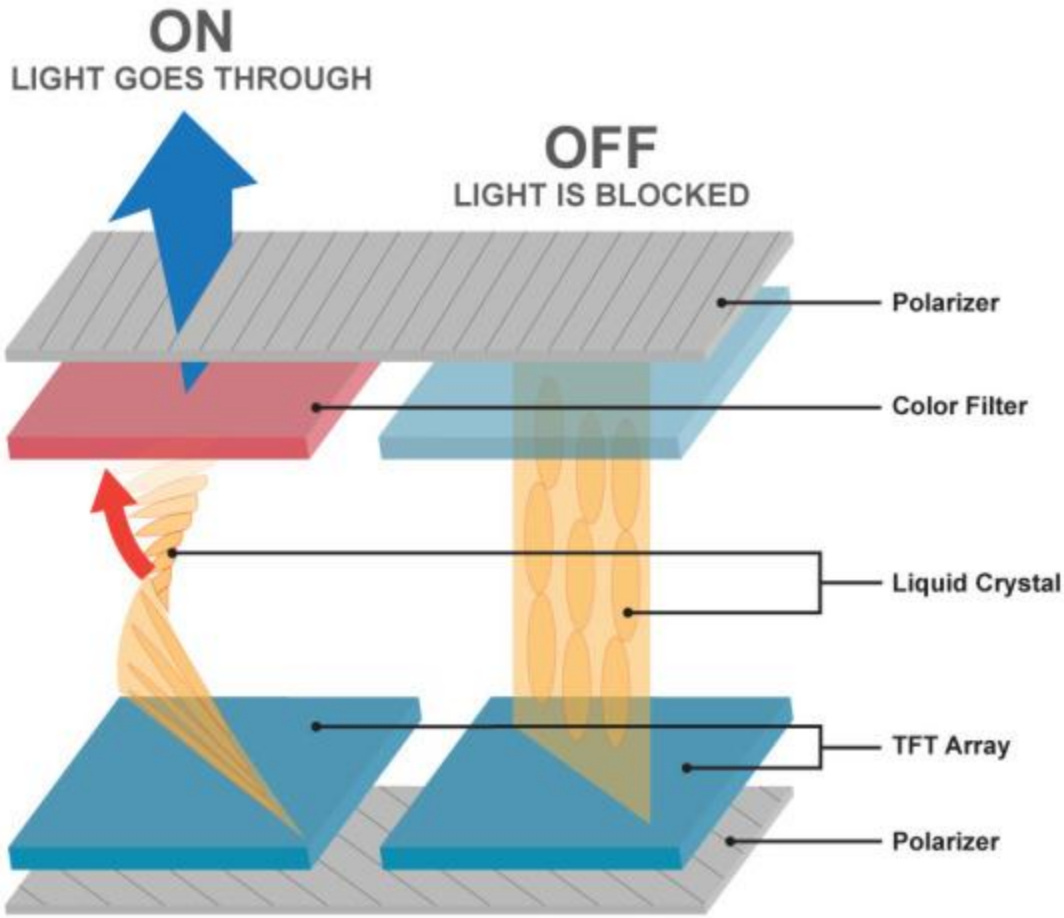
We'll start by discussing the simplest and most common form of LCD panel, twisted nematic.

## LCD: Twisted Nematic (TN or TN-Film)

TN display panels are inexpensive and easy to mass-produce. They're also quite fast, with response times as low as 2 milliseconds. That's nowhere near as fast as OLED or plasma displays, but it's by far the fastest of the LCD types. A fast response time reduces blur on rapidly moving objects and enables high refresh rates, which is often necessary for 3D displays.

Unfortunately, TN panels also produce the lowest overall image quality. They have a narrow color gamut (that is, they don't display as much of the total color spectrum as other technologies do). Typically each subpixel element can display 6 bits of brightness, meaning you can combine only 64 shades of red, green, and blue to produce colors. Most TN panels get around that limitation through a process known as "dithering," in which adjacent pixels display slightly different colors. If the display is unable to reproduce a certain shade of blue, for instance, one pixel shows a slightly darker shade of blue, while an adjacent pixel shows a slightly lighter shade. The idea is that your eye then averages the two and "sees" the shade of blue that the display can't re-create. Some displays switch a single subpixel very quickly between two different voltages, rapidly toggling back and forth between a lighter and darker shade, to simulate an in-between color.

TN panels have poor viewing angles. From the sides, colors may shift. If you look at the display from below, typically the panel darkens, and if you look from above, it washes out. You can see this effect on almost any laptop, as most notebooks use TN panels: Tilt the lid back and forth, and watch how the brightness and contrast shift.




TN panels “twist” polarized light so it is either blocked by or shines through another polarizer.

**How it works:** Let’s start with the light source. This can be a mirror in the case of reflective LCDs, or a light such as a CCFL (cold cathode flourescent lamp) or LED (light-emitting diode). The light first passes through a polarizing filter, which aligns the light waves in one direction. Then it passes through the TN liquid crystal. The molecules of this crystal are special in that they “twist” the light 90 degrees as it passes through. Next the light passes through a color filter, which tints the light red, green, or blue. Finally the light reaches a second polarizing filter, oriented 90 degrees to the first one. If it weren’t for the TN crystal, this second filter would block all light; but since the TN crystal twists the light so that it is aligned to the polarizer, it all passes through.
When a current is applied to the liquid crystal, it “untwists,” changing the light’s orientation and causing more of it to be blocked by the second polarizing filter. The more current that is applied, the more the liquid crystal untwists and the more light is blocked.

Each pixel of a TN panel consists of three rectangular subpixels: one red, one green, and one blue. By varying the current to each of the crystals in these subpixels, you can mix the three colors to produce many different hues.

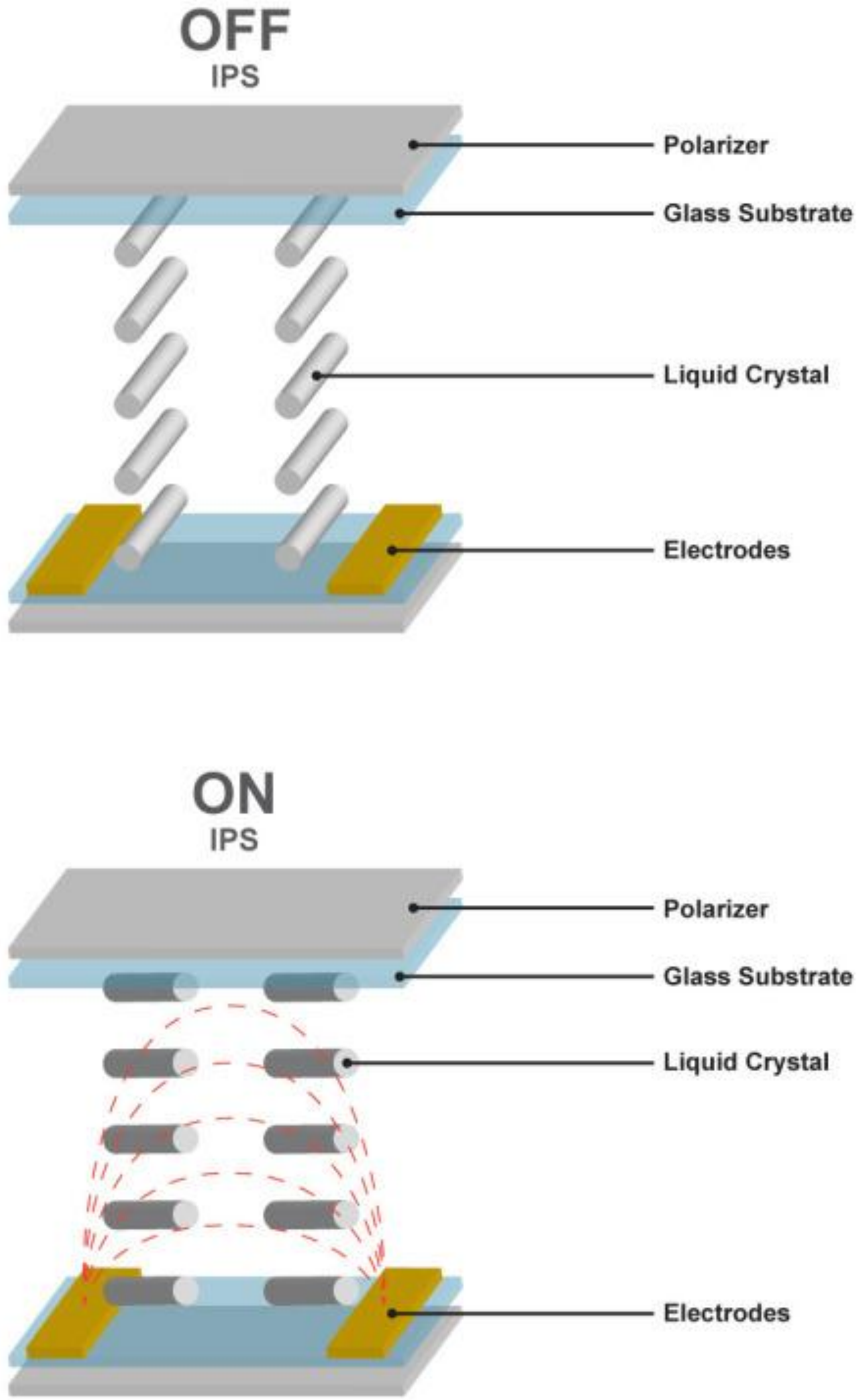
## LCD: In-Plane Switching (IPS)

Hitachi developed IPS technology in 1996 to combat the laundry list of problems afflicting the TN panels of the day, especially poor color reproduction and limited viewing angles. Since then the technology has undergone tweaks and improvements with variants such as Super IPS (S-IPS), Advanced Super IPS (AS-IPS), and IPS Pro. Today most IPS panels use some sort of enhanced variant, but are still generally called “IPS.” These days LG Display produces the majority of IPS panels.

IPS displays have several major advantages over those that use the more common and less expensive TN technology. Each red, green, or blue subpixel can display 8 bits (256 levels) of brightness or more, giving the display more-accurate color without resorting to tricks like dithering. IPS displays are capable of a wider total range of color, as well. For that reason, photographers and artists tend to favor them; most “professional” desktop PC monitors made for photography, design, print layout, and other color-sensitive tasks use IPS panels.

Viewing angles are much wider on IPS panels, too. You’ll see proper color and contrast when looking at them from almost any angle, which makes them quite useful on smartphone and tablet displays. Apple’s iPads, the iPhone 4 and iPhone 4S, the Amazon Kindle Fire, and the Asus Eee Pad Transformer are just some of the mobile products using IPS displays.

It’s not all upside with IPS technology, though. Generally IPS displays aren't as bright as comparable TN panels, and they don’t change state quite as quickly. Thus, it’s not yet possible to get the nice 120Hz refresh rates necessary for most 3D displays, and fast-motion graphics can sometimes leave a bit of a trail or “ghost” behind; modern IPS panels have minimized that problem, but they’re still not nearly as fast as TN panels. They’re also more expensive in general.




IPS displays keep crystals aligned with the plane of the display, so they look the same from all angles.

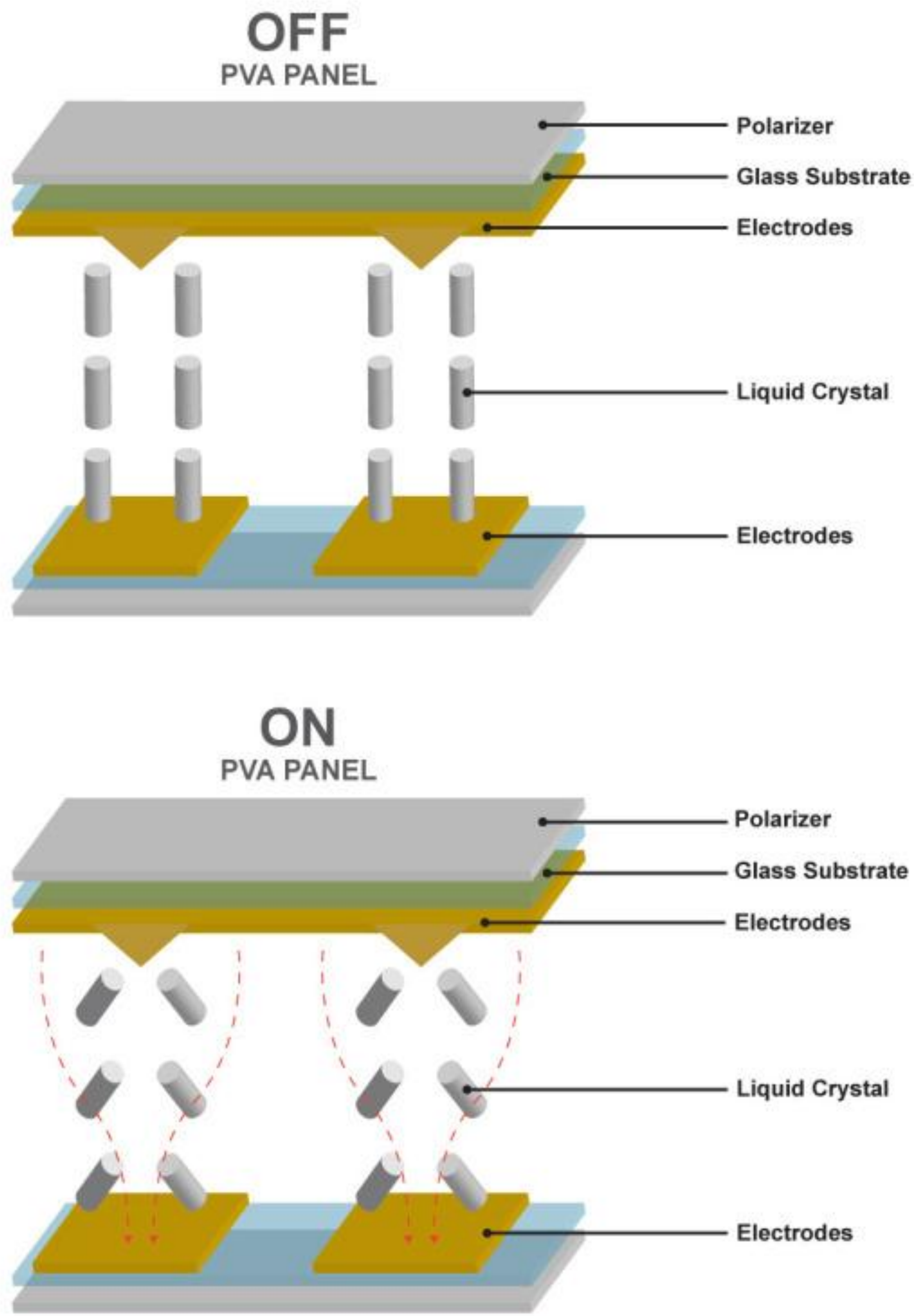
**How it works:** The structure of an IPS panel is very much like that of the TN panel explained earlier. The crystal structure is different, with all the crystals aligned horizontally (hence "in plane" with the display). As opposed to TN panels, where one electrode is beneath the crystal and one is above, IPS displays require both electrodes to be beneath the display, taking up more room. This design allows a little less light to pass through, making the display a bit dimmer even when the backlight is shining just as brightly.

When current passes through the crystal in an IPS display, the crystal structure rotates 90 degrees in parallel with the flat plane of the display, rather than turning vertically from parallel to perpendicular. The crystal turns further as more voltage is applied, letting more of the backlight shine through.

## LCD: Vertically Aligned (VA)

Somewhere in between IPS (slower and dimmer, but very high quality) and TN (brighter with higher speed, but lower quality) you'll find vertically aligned displays. Generally they have better color reproduction than TN panels do, and they can display 8 bits of brightness per subpixel, but they don't produce quite as wide of a color space as IPS does. Viewing angles are generally much wider than those of TN, but not quite as wide as what you see on IPS. Response times are, again, somewhere between those of the other two technologies.

You'll hear a couple of different terms for VA panels, such as MVA (multi-domain vertical alignment) and PVA (patterned vertical alignment), which refer to slight variations on the technology. Modern VA panels all produce excellent, dark blacks and thus deliver very good contrast ratios. The Toshiba Thrive boasts an "IPS-like" display (according to Toshiba marketing), but it appears to have a VA panel.




VA displays offer better viewing angles than TN displays do, and they produce deep blacks.

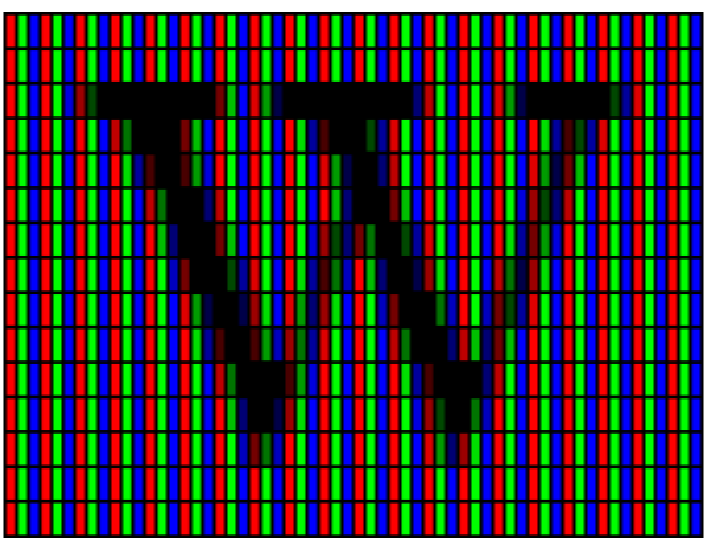
**How it works:** The general structure of a VA panel is very much like that of a TN panel; only the crystal structure differs. When no voltage is applied, the crystals are lined up perpendicular to the display (hence “vertically aligned”), blocking all light from the backlight. When a charge is applied, the crystals switch to align horizontally, allowing light to pass through.

MVA and PVA panels have various crystals throughout the lattice skewed to different angles, so you get the same results when you look at the display at an angle.

## What About Those Other Terms?

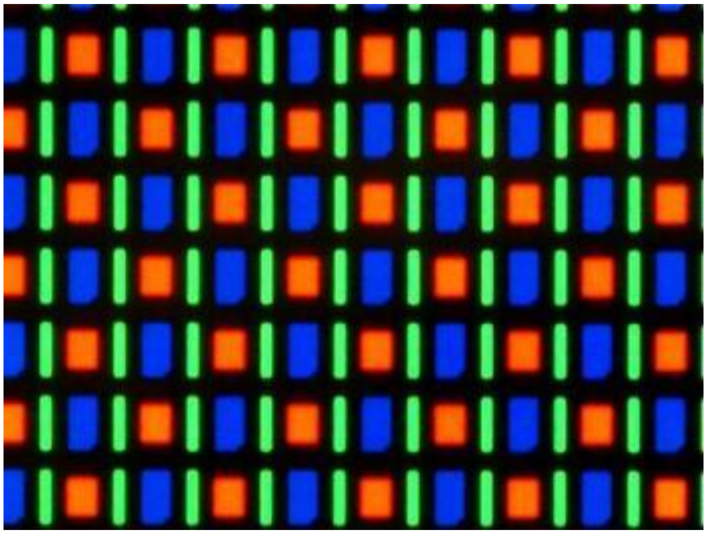
You'll encounter a lot of other confusing acronyms, initialisms, and terms when reading about digital displays. There are too many technical terms and marketing buzzwords to list them all, but here's a brief description of some of the more common ones.

**LED:** The light behind an LCD panel is one of two major varieties. The first type is CCFL (cold cathode flourescent lamp), a technology that's sort of like the fluorescent bulbs in your home, only thin and flat. The other type is LED (light-emitting diode). Using LEDs typically gives a TV a wider color range, a longer life, and lower power consumption. Some TVs have LEDs only along the edge (marketed as "edge-lit LED"), which is less desirable because it makes achieving high brightness and even lighting difficult.
**TFT:** A thin-film transistor is a thin substrate, like glass, coated with various thin films of metal, silicon, or plastic. The idea is to form a big sheet of very small switching transistors and capacitors. It's simply a means of changing the current applied to individual pixels on a display--virtually all active-matrix displays, from AMOLED displays to nearly all LCDs, use TFTs.
**Active matrix:** This is a system for individually controlling each subpixel with a series of transistors and capacitors (see: TFT). It allows for more precise voltage control and faster switching than passive-matrix technology does. Nearly all digital displays today are active matrix.
**Passive matrix:** This technology controls the voltage of individual subpixels with a simple grid of conductive materials. Almost no LCD uses this form of addressing subpixels anymore, since the price of TFTs has dropped and the quality has improved. Passive-matrix technology generally produces less precise control over color and pixel response than active-matrix technology does.



An arrangement of standard red, green, and blue subpixels.

**Subpixel:** On all digital displays, a single pixel (one picture element meant to be able to represent any color) is actually formed of several smaller subpixels. Typically each pixel consists of red, green, and blue subpixels; the display alters the brightness of these three colored subpixels to produce any color or shade. Because the subpixels are too small to see individually, our eyes see the combination of the three subpixels as one blended color. Some displays have a fourth subpixel color (usually white or yellow), but that isn't very common.



The PenTile arrangement of subpixels on the Google Nexus One's AMOLED screen.

**PenTile:** The red, green, and blue subpixels that form a single pixel on a digital display are usually long, evenly sized rectangular stripes. In PenTile displays, the subpixels are not identical, but instead have different sizes and shapes. The PenTile arrangement works in conjunction with a specially designed display controller that takes the irregular number and size of these subpixels into account. The goal is to produce a greater number of effective pixels with fewer subpixels.

Defining the resolution of a PenTile display has been the subject of some controversy, as the technology relies on using some subpixels in two neighboring pixels. The Google Nexus Onesmartphone prominently featured an AMOLED display with a PenTile subpixel arrangement. PenTile is a trademark of Samsung.

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